Anatomy of a Mountain: The Thebes Limestone Formation (Lower Eocene) at Gebel Gurnah, Luxor, Nile Valley, Upper Egypt

by

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Abstract

We present a detailed geologic study of the Thebes Formation at Gebel Gurnah in its *locus typicus* on the West Bank (opposite Luxor) of the Nile River in the Upper Nile Valley, Egypt. This is the first detailed measurement and lithologic description of the ~ 340 m thick (predominantly) carbonate section. The Thebes Formation is divided into thirteen major lithic units (A to M). We interpret data on the lithologic succession and variations, whole rock/clay mineralogy, and macro/micropaleontology in terms of deposition on a shallow carbonate platform episodically influenced by continental runoff, and describe six depositional sequences that we place in the global framework of Lower Eocene (Ypresian) sequence stratigraphy. We note however significant incompatibilities between the Thebes depositional sequences and the global sequences. We emend the definition of the Thebes Formation by defining its top as corresponding to level 326 m at the top of Nodular Limestone 'L' (NLL), and assigning the overlying beds to the Minia Limestone Formation. New biostratigraphic data and revision of previous studies establish the direct assignment of the Thebes Formation to planktonic foraminiferal Zones E4/P6b (upper part), E5/P7 and (indirectly) Zone E6/P8, and (probably, indirectly) Zone E7a/"P9", and to calcareous nannofossil Zone NP12 and lower Zone NP13 of the Lower Eocene (Ypresian) and provide a temporal framework spanning ~ 2.8 Myr from <52.45 to ~49.6 Ma for the deposition of the Thebes Formation prior to the prominent sea level fall (~ 49.6 Ma) towards the end of the Early Eocene. Dominantly carbonate deposition, with a strongly reduced detrital influx, occurred on a very wide shelf (probably) at least ~ 100 km from the coastline. The thick sedimentary succession and the marked vertical lithologic variations are interpreted as resulting from sea level fluctuations imprinted on a long-term decrease in sea-level associated with rapid subsidence reflecting tectonic relaxation after the major Late Paleocene tectonic reorganization of the Syrian Arc.

Key words: Thebes Limestone, Lower Eocene, Gebel Gurnah, Egypt, sequence stratigraphy.

I- Introduction

The Lower Eocene* Thebes Formation is one of the thickest (~340 m) and regionally extensive outcropping lithostratigraphic units of Egypt (Snavely et al., 1979; Fig. 1). Extending from the Farafra Oasis in the west to Upper Egypt (mostly between Qena-Esna) and beyond to the Red Sea coast and the Sinai in the east (Fig. 2), it forms hills and plateaus that dominate the

Egyptian landscape. It represents part of the extensive carbonate platform developed along the southern margin of the Tethyan Ocean, which Said (1962) has called the “stable platform”. Despite this vast distribution, the geology of the formation remains poorly elucidated, and contradictory interpretations have been given of its age and depositional environment. The type section of the Thebes Formation is at Gebel Gurnah, in the prominent limestone cliffs on the west side of the Nile Valley, opposite the town of Luxor, which form the “Thebes Mountain” (Fig. 3). Since formal designation by Said (1960) the few published studies of the formation have concentrated mainly on aspects of its paleontology, with limited analysis of lithostratigraphy and depositional environments. However, there has been renewed interest in the rocks of Gebel Gurnah in recent years, particularly in their physical, chemical and geotechnical properties, in connection with efforts dedicated to the conservation of the tombs (e.g., Rutherford et al., 1977; Curtis, 1979; see Aubry et al., 2008, 2015, 2016). The Thebes Mountain was a sacred area during the 18th to 20th Pharaonic dynasties (~1539-1075 BC) and it is now a World Heritage Site, constituting one of the most famous archaeological sites in the world, with hundreds of tombs and large funerary temples at the foot of the mountain. Most of the tombs were cut into the limestones of the formation, including those located in the extensive tilted blocks lying in front of the Theban cliffs (Aubry et al. 2009, 2016; Dupuis et al., 2011). Endorsed by the Supreme Council of the Antiquities of Egypt (SCA), the Thebes International GeoArcheological project (TIGA; Said et al., 2004; Aubry et al., 2009) was formed to investigate more fully the geology of Gebel Gurnah and adjacent areas, particularly with relevance to conservation programs for the tombs. The first phase of this project included detailed lithologic logging, identification of key beds and their topographic expression, and their relationship to the tombs (Aubry et al. 2011, 2016; Dupuis et al., 2011). In this paper, we document in detail the lithology of the Thebes Formation, identify lithostratigraphic horizons useful for local and regional correlations (as used in establishing a geological map of the West Bank at Thebes; Dupuis et al., 2011), provide data on lithofacies, mineralogy, paleontology and sequence stratigraphy, and discuss its depositional context and age. Based on our findings we emend the definition of the Thebes Limestone (Said, 1960) by defining its upper boundary and apply the name of *Thebes Limestone Formation* of El Naggar (1966) to the emended definition of the formation.

We include four appendices which cover the following topics: 1) historical review of lithostratigraphic terminology of the Thebes Group and adjacent units ; 2) extension (recognition and correlation) of Lower Eocene litho-and biostratigraphy from the Upper Nile

Valley (Dababiya Quarry, Theban Necropolis) to the Western Desert (Farafra Oasis section); 3) historical review of planktonic and larger benthic foraminifera stratigraphy of the Thebes Formation on the West Bank ; and 4) estimated biochronology of Theban depositional and sequence stratigraphic history and events and calcareous biostratigraphy.

The Thebes Formation constitutes a substantial part of the substratum of the Thebes Mountain (aka Gebel Gurnah), and the lithologic log presented here constitutes a much needed geoarcheological resource. It will be particularly valuable for archeological research in the Necropolis of Sheikh Abdel Gurnah which is famous for its beautiful tombs of the Nobles in this displaced structural block where most tombs have been cut in Lithological Units A to K of this paper.

II- Historical background

The geology of the Thebes area attracted the interest of geologists as early as 1863, when Delanouë (1868) published the first lithologic observations. Zittel (1883, p. 102-103) included a section of Gebel Gurnah, comprising the claystones of the (present-day) upper Esna Formation (his unit 5), and the limestones of the overlying Thebes Formation (his units 4 to 1) which he assigned to the *unter Libysche Stufe*. Zittel (1883) and other authors, until the mid-twentieth century, relied largely on macrofossils (molluscs, echinoids) and larger foraminifera in dating and correlating the Eocene succession in Egypt. Cuvillier (1930, fig. 5, pp. 58-60) included a graphic section and description of the Gebel Gurnah section, dividing it into six lithologic units, again listing molluscs, echinoids and larger foraminifera, with some comments on the biogenic components of the limestones as seen in thin-section. Zittel (1883) and Cuvillier (1930) interpreted the Esna Shale Formation as Late Cretaceous and the Thebes Formation as Early Eocene. While conducting the first studies of planktonic foraminifera at Gebel Gurnah Said (1960) gave a brief summary of the section, largely updated subsequently by Said (1962, p. 93) with different bed numbers. This was itself essentially relying on Cuvillier (1930), with some updating of fossil names.

An important (but unfortunately unpublished) study of the section was made by Hamam (1971) who subdivided the exposed succession (from the base upwards) into a “Unit I: Upper Owaina Shale, ~3 m” followed in stratigraphic order by Unit II: Thebes Calcareous Shale (~ 42.64 m); Unit III: white chalky Limestone (~ 116.5 m); Unit IV: (bed 5): white marly limestone with *Lucina* *thebaica* (~ 65.5 m); (beds 6-8): white and yellowish-white limestones with larger benthic foraminifera (~30.5m); Unit V (beds 9-12): white chalky and/or cherty limestones with scattered larger benthic foraminifera (~115 m); and Unit VI (beds 13-23): yellowish-white thin-bedded limestones (~ 77.5 m). Units I and II are now included in the Esna Formation. Hamam noted (1971, p. 5: see also his fig. 9) that Said [and Cuvillier] apparently overlooked the uppermost exposed part of the Thebes Formation at the top of Gebel Gurnah, which we have not confirmed in this study.

Curtis (1979), in an unpublished but widely cited report (e.g., by Aubry et al. 2009, and Tawfik et al. 2010), divided the Thebes Formation into four members (I to IV) based on major lithologic and topographic boundaries. His stratigraphic section was later published in Curtis (1995, fig. 1). Aubry et al. (2009) briefly discussed the stratigraphic succession, refiguring Curtis' section. Tawfik et al. (2010, fig. 2) also used Curtis' scheme, with their log differentiating within it approximately 20 smaller-scale lithologic units in the Thebes Formation. Clay mineralogy, X-ray diffraction mineralogical analysis and petrographic analysis in that study were carried out on samples covering almost all these lithologic units. Boukhary et al. (2011, fig. 4) provided a more generalized stratigraphic section.

Dupuis et al. (2011) divided the Thebes Formation of Gebel Gurnah into five informal lithologic units (1 to 5), with boundaries corresponding to the 'stepped' profile of the SE face of the mountain (Dupuis et al., 2011, figs. 3, 4). These correspond to Curtis' units I to IV. The lithologic subdivisions previously proposed are compared with the scheme proposed here in Figure 4. These largely correspond to topographic features, easily correlatable in the field.

Said (1960) determined the upper Esna Formation to belong to the 'Landenian' [Thanetian] Stage and the Thebes Formation to the Ypresian Stage. These conclusions were disputed by some later workers (e.g. Tawadros 2001, p. 131), but have been validated here and elsewhere by subsequent work on planktonic foraminifera and calcareous nannofossils, and the more recent formal definition of the Paleocene/Eocene (Thanetian/Ypresian) boundary which now also places the upper Esna Shale Formation in the Ypresian Stage (Dupuis et al. 2003; Aubry et al., 2003; Aubry et al. 2007).

The lithostratigraphic framework for the Lower Eocene deposits of Egypt is complex and controversial with several lithostratigraphic terms used in addition to Thebes Formation. In addition, recognition/extension of lower Paleogene litho-and biostratigraphy from the central and upper Nile Valley to the Western Desert has remained a contentious issue among geologists for many years. Both issues are reviewed in Appendices 1 and 2. Below we recount briefly the lithostratigraphic subdivisions that have been proposed at Gebel Gurnah (Table 1).

Said (1960) introduced the name “Thebes Formation” for the “290-meters thick limestone section with many flint-bands that overlies the Esna Shales at Thebes”, whereas the “Esna Shale” was described by Beadnell (1905) for “laminated green and gray shaly clays” between the Tarawan Chalk and the Thebes limestone. This is the lithostratigraphic framework used here, slightly modified by assignment of the “Esna Shales” to the “Esna Shale Formation” (Dupuis et al., 2003) and the renaming of the “Thebes Formation” as the “Thebes Limestone Formation” (El Naggar, 1966).

Alternative lithostratigraphic frameworks have included replacement of the name “Thebes Formation” by “Luxor Formation” with inclusion of the Thebes Formation as its upper member overlying the Qurnah Calcareous Shale Member (El Naggar, 1970; see also Perch-Nielsen et al., 1978, fig. 3). The Luxor Formation, in turn, overlies the Upper Owaina Member of the Owaina Shale Formation (El Naggar, 1970). The latter also corresponds to the lower part of the Esna Shale of Said (1960). This subdivision was followed, for instance, by Perch-Nielsen et al. (1978) for whom the base of the Thebes Limestone Member is the same horizon as Said’s base of the Thebes Formation. El Dawoody (1984, 1993) departed markedly from this correlation by including the Thebes Limestone and the Gurnah Calcareous Shale (renamed the Thebes Calcareous Shale) in the Thebes Limestone. In spite of these differences, the lithostratigraphic subdivision of the Lower Eocene succession at Gebel Gurnah has now been stabilized with the Thebes Formation overlying the Esna Shale Formation.

III- Location, Section, Methodology

III-a- Location

On the West Bank of the Nile, opposite Luxor, the Sahara plateau nearly reaches the alluvial plain (Fig. 3). There, prominent cliffs mainly constituted by the subhorizontal outcrops of the Thebes Formation run about 5 km parallel to the river culminating between 455 and 478 m at Gebel Gurnah (El Qurn). Low-lying hills lie along the vertical 100 m high cliff that marks the base of the Gebel (Figs. 3, 5) and corresponds with the first unit of the formation. These low reliefs that descend gradually, stepwise, towards the flat alluvial plain of the Nile correspond to the three generations of tilted blocs (Dupuis et al., 2011). The youngest/ higher ones (167-250 m) are spatially separated at the foot of the lower cliff. The oldest/lower and more or less residual blocks disappear among the fluvial terraces fringing the alluvial plain. Deeply incised valleys enter the plateau cutting down through the underlying Esna Shale and offering large favorable exposures (Said, 1962, 1990; Fig. 5).

III-b- Measurement and description of the reference section

Following extensive fieldwork on the West Bank (by C. Dupuis), a composite reference section (~ 340 m) was selected along the Theban cliffs, extending from the formational contact between the Thebes and the underlying Esna Shale in a saddle between the Valley of Colors and the amphitheater of Deir El Bahari and up to the summit of El Qurn (Dupuis et al., 2011, fig. 6; Figs. 5-7). Because of local inaccessibility as a result of steep slopes and thick cover of screes, it was not possible to log a single vertical section. Instead, eleven partial sections were measured, described and sampled in the best exposures of the formation. These partial sections were carefully correlated on the basis of cliff-forming lithologies as well as distinctive lithologies such as flint layers and marly beds (see below). All measurements along the section (e.g., + 62.5 m) are in reference to the Thebes/Esna Shale formational contact. Although attention was given to documenting the Gebel Gurnah succession from its best exposures along the Theban cliffs, several lithologic intervals (in particular marls) were concealed under screes. Therefore, an auxiliary section was logged in the tilted block of Sheik Abdel Gurnah (Dupuis et al., 2011, fig. 6; Fig. 6a). We did not observe any major lateral lithologic variation between the frontal cliffs and the outcrops in the tilted block. Also, the upper 50 m of the section were extremely difficult to describe along the main measured profile because of its steepness. The youngest strata of the Thebes Formation were thus measured ~300 m west of El Qurn along an easily accessed pass (labelled ELQC in Figs. 5, 6b).

The section was first measured by C. Dupuis and W. Fathy with a Jacob's staff that corrects for the dip of the rocks. The Thebes Formation is subhorizontal in the plateau, but its NW-SE dip varies between 20° and 40° in the Hills of Sheikh Abdel Gurnah. The thickness of some marly beds varies from place to place because the marls were partially 'squeezed out' or acted as slip planes in cambered areas of the tilted block. Minor faulting was encountered along the section and careful corrections were made to the thickness of affected strata. It was measured a second time by R. Knox and C. King for control as the section was being described.

The logging of the section is based mainly on macroscopic examination, aided by low-power magnification (hand-lens), where needed. The Thebes Formation is mostly comprised of limestones (Fig. 8). These were described based on texture (e.g., fine, bioclastic), petrographic characters (e.g., marly, siliceous, phosphatic), bedding (e.g., thickness of beds, nodular, concretionary), mineralogy (whole rock and clay mineralogy) and paleontology (macrofossils: e.g., bivalves [*Venericardia*, *Spondylus*, *Lucina*, oysters], gastropods [turritellids]; microfossils: e.g., *Nummulites*, radiolarians). Flints are pervasive in these limestones and present a broad diversity of size, shape, and distribution. Omission surfaces were carefully identified (Fig. 8). Petrographic analysis has not been carried out, but petrographic data from published sources have been incorporated in the descriptions below.

III-c- Whole rock mineralogy and clay mineralogy

Few studies have dealt with the clay content and mineralogy of the Thebes Formation. In a paper mainly devoted to differential thermal and thermogravimetric analysis, Saad et al. (1980) used some DRX and geochemical data to document the mineralogic composition of the Esna Shale Formation and lower part of the Thebes Formation (Cliffs 1 and 2, Subunits A1 to B5) outcropping behind the Temple of Hatshepsut at Gebel Gurnah. They did not determine the presence of fibrous minerals, only that of montmorillonite and kaolinite in the Esna Shales and kaolinite or montmorillonite in the Thebes limestones. In a more recent study, also at Gebel Gurnah, of the clay mineralogy of the upper Esna Shale Formation and the Thebes Formation, Tawfik et al. (2010) concluded that the most important change in the succession was a shift from the smectite-dominated Esna Shales, with significant proportions of illite and kaolinite, to the abrupt appearance at the base of the Thebes Formation of high proportions of sepiolite and palygorskite and the simultaneous disappearance of illite and kaolinite. They showed that sepiolite and palygorskite occur in significant proportions throughout most of the formation, together dominating the clay, and that smectite remains relatively common at its base, although decreasing steadily upwards and eventually disappearing in Unit H. Detailed mineralogic analyses of the Dababiya Quarry section have shown that sepiolite and palygorskite appear already in the upper part of the Esna Formation (in the Qurnah Calcareous Shale Member herein; see below), increasing to dominate the assemblage in the basal units of the Thebes Formation (Dupuis et al., 2003; Ernst et al., 2006). Kaolinite disappears at the same level as sepiolite and palygorskite appear. Considering the discrepancies between results in these different studies we have considered it important to reinvestigate the mineralogy of the Thebes Formation.

Sixty samples (identified as Th-n) collected in the Gebel Gurnah section and in outcrops in the hills of Sheikh Abdel Gurnah were selected to determine the broad characters of the whole rock and clay mineralogy of the Thebes Formation. Fifty-seven of these were retained for analysis (Table 2).

<u>Whole rock mineralogy</u>

An aliquot of each sample was finely powdered and placed in a special device for randomly oriented X-ray diffraction (XRD) analysis. One XRD per sample was interpreted using the standard methodology in Pletsch (1997, page 25). The XRDs provide an approximate quantification of the main minerals of the rocks. For sepiolite and palygorskite, we assumed a reflective power of 1.

Small quantities of gypsum, anhydrite and halite were recorded sporadically. Gypsum and anhydrite, which are omnipresent in the outcrops as small veins, are interpreted as weathering products of pyrite and they are not regarded as primary components of rocks. The presence of halite, which is rather frequent at joints, is due to the current arid climate of Egypt. Neither of these three minerals was considered in the calculation of the composition of the whole rocks.

The only flint (from Subunit B6) that we have analyzed here contains 12% quartz. This quartz is not of detrital origin, but results from diagenetic evolution of biologic silica (opal) that accumulated near the sea floor (probably as chalcedony and/or micro-quartz as usual for flint nodules; McBride et al., 1999). Quartz is a minor constituent of the flint. Few clay minerals are included whereas calcite and ankerite are abundant (83%).

<u>Clay mineralogy</u>

Classical laboratory techniques, methodologies and procedures were adapted from Holtzappfel (1985). Samples were first decalcified using a 10% HCl solution and then deflocculated. The <2 µm fraction was extracted by decantation and deposited on glass slides to obtain conveniently oriented aggregates (001 phyllosilicate reticular plane parallel to the slide). Three slides per sample were prepared, each being submitted to three different treatments. One slide was left to dry in the ambient environment. The second was solvated by glycol vapor (glycolated). The third was heated at 490°C for 2 hours. These three complementary treatments allow determination of the behavior of clay minerals upon which mineralogical identification is based. A Siemens diffractometer Crystalloflex D 5000 was used to establish the diffractograms (three per sample: natural, glycolated, heated). The intensities (I) of characteristic clay mineral peaks were used for semi-quantitative determination of their abundance. Is are measured based on heights above background.

<u>SP* percentage</u>

The two fibrous, Mg-rich clay minerals sepiolite (S) and palygorskite (P) are dominant in much of the Thebes Formation. These minerals are known to form in soils and calcretes under arid climatic conditions, and in playa deposits under sub-evaporitic conditions (Velde, 1995; Weaver, 1989). In the fully marine depositional environment, where the sediments that would become the Thebes Formation were deposited, these fibrous minerals would have formed through direct precipitation from interstitial/bottom circulation of Mg-enriched solutions that originated on land under sub-arid conditions (Millot, 1962; Isphording, 1973; Thiry and Jacquin, 1993). Building on Slansky et al. (1959) who described a seaward replacement of the clay succession from kaolinite (nearshore) to montmorillonite, palygorskite and (deeper in the basin) sepiolite, Isphording (1973) determined that "this gradation would correspond to an increase in the $MgO:Al_2O_3$ ratio with distance from shoreline". The balance between sepiolite (with Mg) and palygorskite (with Mg and Al) should therefore reflect the basinward/landward increase/decrease of the Mg/Al ratio. We use here the SP* percentage (SP*=S/S+P x 100) as an indicator of distance from shore and of the strength of continental influence on epicontinental deposition. When the percentage is low, palygorskite dominates and deposition took place nearer the continent than when the ratio is high, implying that sepiolite dominates in sediments deposited rather far away offshore. In short, a low SP* indicates that deposition took place in a proximal position with Al transfer to the clay, whereas a high SP* percentage indicates a more distal depositional setting.

<u>A note of caution</u>

It is important to recognize that our interpretations below are somewhat biased by both our sampling and laboratory procedures. First, nearly all the samples we have selected for analysis are of limestone. Although flints are very abundant in the Thebes Formation (see below), only one flint (TH122.9 from the lower part of lithologic Subunit B6, which is homogenous limestone with few, interbedded flints) was analyzed (Table 2). Second, it is difficult to compare results from analysis of the clay content derived from the powdered whole rock DRX with results obtained through relative quantification of the <2 μm fraction. In the first case, the clay fraction is essentially mineralogical. In the second case, quantification concerns only the <2μm size fraction of the rock. In addition, identification and quantification of small amounts of illite, chlorite and kaolinite are difficult in the presence of abundant fibrous minerals (sepiolite and palygorskite) and this requires cautious treatment of the data.

III-d- Micropaleontology: Sampling, sample preparation and methods

Approximately 140 samples were collected for microfaunal analysis (planktonic and benthic foraminifera), avoiding the more indurated intervals. Fifty three samples were selected among them for planktonic foraminiferal and forty nine for calcareous nannofossil analysis.

<u>Microfaunal analysis</u>: Many samples were barren or yielded only indeterminate specimens. All intervals are variably indurated, and most samples required mechanical crushing in order to liberate foraminifera and ostracodes; in most cases the recovered specimens were fragmentary or partly encrusted by sediment. Identification of taxa and calculation of planktonic/benthic foraminifera (P/B) ratios have thus been imperfect.
Difficulty in obtaining clean residues, due to variably indurated lithologies and adherent matrix on free specimens, has inhibited detailed analysis of both benthic and planktonic foraminiferal assemblages. Planktonic foraminifera are represented in almost all productive samples up to 238 m (mid-Unit H), but have not been recorded at higher levels. This is consistent with the results of Hamam (1971; see Appendix 3). The proportion of planktonic foraminifera relative to the total foraminiferal assemblage has been calculated for samples from the uppermost part of the Esna Shale Formation and the Thebes Formation, where preservation is adequate; the accuracy of this data is relatively limited, but clear trends can be demonstrated (see below). Benthic foraminiferal assemblages have also been used for paleobathymetric determination using Van Morkhoven et al. (1986).

<u>Nannofossil analysis</u>: 49 samples were examined in light microscopy for zonal determination. The lowest sample is from the base of the section (0 m; base of Unit A), the highest sample from 316.5 m (base of Unit L). The samples were chosen to avoid, as far as possible, the more indurated lithologies, hence their rather irregular spacing in some intervals. Smear slides were prepared for all samples from cleaned fragments of rock, and analyzed with a Zeiss standard light microscope at magnifications of 600x and 1250x. Simple abundance corresponds to the total number of specimens of each taxon recorded in each preparation (726 mm^2).

Magnifications 600x and 1250x were used for samples with diversified assemblages. In addition, magnification 312.5x was used to locate nannofossils in samples with scarce, poorly preserved assemblages. The counts were primarily established in bright field because the Lower Eocene zonal markers are non-birefringent; complementary analyses were conducted using polarized light. Asteroliths other than *Heliodiscoaster kuepperi* (generally common) were counted to compare their frequency with that of the marker species.

III-e- Zonal frameworks and biochronology

<u>Planktonic foraminifera</u>

The E-zonal scheme of Berggren and Pearson (2005, 2006a) as emended/modified slightly by Wade et al. (2011, p. 138) is used here, as it applies well to tropical and subtropical biostratigraphies. The Thebes Formation belongs wholly to the Lower Eocene (Ypresian Stage). Discussion below is accordingly/essentially confined to the Lower Eocene part of the zonal biostratigraphy; biostratigraphic equivalency to the P-zonal scheme of Berggren and Miller (1988) and Berggren et al. (1995) from which the E-zonal scheme is derived, is given for the sake of continuity and clarity. In the discussion below, LO and HO stand for Lowest Occurrence and Highest Occurrence, respectively.

The Lower Eocene is bracketed by planktonic foraminiferal Zones E1–E7b (lower part) (= P5 [upper part] – "P9" [upper part]). The biostratigraphic interval relevant to the discussion here of the Thebes Formation is shown in Table 3. Zone E7 has been emended/subdivided (Wade et al., 2011, p. 138) into two subzones, a lower Subzone E7a [=P9; *Acarinina cuneicamerata* Subzone) which is the interval between the LO of the nominate taxon and the LO of *Turborotalia frontosa*; and an upper Subzone E7b (= "P9"; *Turborotalia frontosa* LO Subzone) which is the interval between the LO of the nominate taxon and the LO of *Guembelitrioides nuttalli.* With the recent acceptance by the IUGS of the proposal to place/define the base Lutetian/Middle Eocene at a level equivalent to the LO of the calcareous nannoplankton taxon *Blackites inflatus* (zonal boundary NP14a/b = CP12a/b) at the Gorrondatxe Section, Biscaye Province, Spain (Molina et al., 2011) the Lower/Middle Eocene (Ypresian/Lutetian) boundary is now younger/higher than the LO of *T. frontosa*. It lies within the early part of Chron C21r, with an estimated age of 48.4 Ma (compare with an estimated age of 49 Ma at the top of Chron C22n in earlier versions of the GPTS/IMBS: Berggren et al., 1995).

<u>Calcareous nannofossils</u>

The zonal scheme of Martini (1971) was used, because it applies well to the Lower Eocene in both oceanic and epicontinental environments. Zone NP11 is the interval zone between the HO of *Tribrachiatus contortus* at the base and the LO of *Heliodiscoaster lodoensis* at the top. Zone NP12 is a concurrent-range zone defined by the LO of *H. lodoensis* at the base and the HO of *Tribrachiatus orthostylus* at the top. Zone NP13 is an interval zone. Its top is defined by the LO of *Heliodiscoaster sublodoensis*, marking the base of Zone NP14 which is subdivided in turn into two subzones based on the occurrence of *H. lodoensis* and *H. kuepperi* (Subzone NP14a) and the LO of *Blackites inflatus* (Subzone NP14b). Secondary markers include *Heliodiscoaster cruciformis*, whose range straddles the NP12/NP13 zonal boundary, and *Chiphragmalithus* species with ranges restricted to Zone NP12. The Lower Eocene biozonation introduced by Agnini et al. (2014) is not used here. This is because the base of Zone CNE4 of these authors is defined by the common occurrence of *Heliodiscoaster lodoensis* (which is thus younger than the base of Zone NP12), a species that is extremely rare in the Thebes Formation. In general, abundance patterns are not reliable zonal markers for rocks that yield poorly preserved assemblages. The LO of *Blackites inflatus* is the primary marker for correlation of the base of the Lutetian Stage (Molina et al., 2011).

IV- Lithostratigraphic description of the Thebes Limestone

This is the first detailed analysis of the Thebes Formation in Egypt, and it is important because it concerns the expanded stratotype. We first proceed here with an essentially bed by bed lithologic description of the formation. We then review the different lithologies encountered in it, their paleontological and mineralogical contents and conclude with a discussion of the lithostratigraphic subdivision of the formation. The environmental and biostratigraphic implications of the paleontologic and/or mineralogic contents are discussed further below.

IV-a- Lithologic log of the Gebel Gurnah section.

The detailed log of the section from the contact of the Thebes Formation with the Esna Shale Formation to the top of El Qurn was established primarily by C. King and R. Knox although concomitantly with C. Dupuis and W. Fathy for Unit A. We divide the Thebes Formation at Gebel Gurnah into 13 major lithologic units (A to M), subdivided as necessary into subunits (A1, A2, etc) (Fig. 8a-f).

Unit A (Figs. 8a, b)

Thickness: 93.5 m (0–93.5 m).
Lithology: Compact, very fine-grained, limestone with numerous flint layers; marly at the base (Subunits A1 and A2), becoming indurated towards the top where it is nodular (Subunit A5; "Nodular Limestone A" [NLA]; Fig. 8b). Subunit A1 (0–4.90 m) differs from Subunit A2 (4.90–5.95 m) in being more clayey and poorer in flints. Subunit A3 (5.95–50.30 m) is limestone with relatively few flints at the base (lower 10 m) but with very abundant flints organized in thin layers up to 25.80 m. Flints become more dispersed and rounded above but are succeeded by tabular flints up to the top of the subunit. Subunit A4 (50.30–86.90 m) consists of a more indurated flint-bearing limestone. Its base is a slightly marly and bioclastic bed (50.30–51 m); its top is indurated between 78 and 86.90 m. The subunit contains two thin bioclastic beds at ~57.40 m. The flints vary considerably in shape from small (~1 cm) and rounded at the base and top of the subunit, to elongate and in thin layers in the middle of it. Subunit A5 (86.90–93.50 m) is made of indurated and irregularly bedded limestone becoming nodular in its upper 2 m. The LO of *Anondotia sp.* was recorded in this subunit. However, since the section was logged a single specimen of this bivalve has been encountered in Subunit A1 at Sheikh Abdel Gurnah (C. Dupuis, pers. obs., February 2016).
Lower boundary: Unit A overlies the claystones of the Esna Shale Formation; the sharp contact between the two lithologies is well exposed in section WOB, where it was sampled, and also in the artificially excavated embayment behind the Temple of Hatshepsut at Deir El Bahari.
Upper boundary: It is marked by a prominent thalassinoid-burrowed omission surface.
Remarks: Unit A forms the often vertical Cliff 1 of Dupuis et al. (2011) and is the most prominent topographic feature of Gebel Gurnah (Fig. 6b). A weak notch is visible at about the middle of the cliff, corresponding to the boundary between Subunits A3 and A4. Two thin, tabular flint layers form a distinctive marker at ~2.7 m below this.

Unit B (Figs. 8b, c)
Thickness: 39 m (93.5–132.5 m).
Lithology: This unit is characterized by the low abundance of large flints and the abundance of detrital clay material. The lower part (Subunits B1 to B5) is dominantly argillaceous with a few thin strata of limestone. The upper part (Subunits B6 to B7) consists of homogenous limestone with isolated layers of large (10 cm in diameter) flints. Subunit B1 (93.50–94.0 m) is a thin indurated limestone with abundant phosphate. Subunit B2a (94.0–95.0 m) is mainly a thin red calcareous claystone that passes into an argillaceous limestone (Subunit B2b, 95.0–95.9 m). Subunit B3a (95.9–97.0 m) is also an argillaceous limestone. The two subunits are separated by

a claystone at ~95.9 m. Subunit B3b is a thick (~10 m), grey dolomitic claystone that passes into the hard white limestone of Subunit B4 (108–110.50 m). A layer of flints underlying an omission surface marks the top of this subunit. The 1 m thick Subunit B5 consists of a red marl. Unit B6 (111.50–131.50 m) is a thick (20 m), homogenous limestone with only few flint layers that are interbedded in the lower part of the unit and often vertical in its upper part. Subunit B7 is a prominent 1 m thick limestone with a double layer of large flints.

Lower boundary: It is marked by the prominent omission surface at the top of Unit A.

Upper boundary: It is marked by the double layer of flints underlying 2 m of reddish grey marl.

Remarks: Subunit B1 is particularly well exposed in the southwest facing hills of Sheikh Abdel Gurnah. The step forming the base of Cliff 2 results from the erosion of the overlying argillaceous interval (Subunits B2 and B3a), not previously adequately documented because of being concealed almost everywhere by screes. Subunit B2 was sampled in a temporary excavation for power cables. Subunit B3b, a more indurated ankeritic marl, is well-exposed only in an ancient quarry (section VKA, Figs. 5, 6b).

Unit C (Fig. 8c).

Thickness: 37.1 m (132.5–169.6 m).

Lithology: Mostly homogenous limestone with sparse bioturbation and flints. Subunit C1 (132.5–134.4 m) is reddish grey marl (Fig. 9a). Subunit C2 (134.4–141 m) is a compact limestone with a few layers of large flints (Fig. 9a). An omission surface occurs in its upper part and another marks its top. Subunit C3 (141–141.95 m) is a pink marl (Fig. 9a). Subunit C4 (141.95–169.6 m) is also a compact limestone without apparent stratification except where flint layers occur. It differs from Subunit C2 by the presence in its lower part of dispersed, small (~ 1 cm), spherical, marble-like flints (Subunit C4a) and in its upper part (Subunit C4b) of a bioturbated limestone. The close succession of four layers of flints between 151 m and 153.80 m separates parts a and b of Subunit C4. Subunit 4b is characterized by abundant whitish concretions that occur immediately above its base in an interval rich in small *Venericardia* and with common *Anondotia* (We use indifferently here *Anondotia*, Tellina and *Lucina*, see below). The LO of *Nummulites* in the Thebes Formation at Gebel Gurnah is at 165 m and they are common up to 169.6 m.

Lower boundary: it is marked by the reddish gray marl overlying the double-layered flint limestone of Subunit B7.

Upper boundary: It is a layer of large, subspherical flints (decimeter scale) overlying the *Nummulites*-rich bioclastic limestone (Subunit C4b)

Remarks: Subunit C2 is well exposed throughout the West Bank. It is easily recognized in the landscape where its top corresponds to the top of Cliff 2. For this reason, it is also a landmark in aerial photographs.

Unit D (Fig. 8c).

Thickness: 20.6 m (169.6–190.2 m).

Lithology: This unit essentially consists of a) a succession of concretionary to nodular limestone (up to 175.40 m; Subunit D1), b) limestone with alternating flints and carbonate concretions (up to 181.8 m; Subunit D2), c) compact limestone (up to 186.3 m; Subunit D3) with three characteristic levels (at 182.7, 183.10, and 184.50 m) of embedded concretions that are aligned with the bedding and consist of a hard layer of carbonate surrounding a nucleus of flint, and d) a compact limestone (up to 190.2 m); Subunit D4 with two levels of carbonate concretions (at 186.75 and 188.10 m). Operculines occur at the base (186.5 m) and at the top (189.50 m) of this subunit. Unit D differs from Units C and E in the scarcity of flints. However, abundant semi-tabular flints occur between 176.7 and 180.50 m in Subunit D2, large subspherical flints at 181 m also in Subunit D2, dispersed flints of variable size between 182.5 and 186.40 m in Subunit D3, and rare, small flints are aligned with stratification at 187.80 m in Subunit D4.

Lower boundary: It is marked by two successive bioclastic limestone beds containing shell debris, including oysters.

Upper boundary: It is well marked by the succession of two thin prominent beds of limestone (Subunit D4) immediately below a thick (9.60 m) interval of nodular limestone (Subunit E)

Remarks: The contact between Subunits D1 and D2 is located at the base of a nodular bioclastic limestone at 175.4 m; that between Subunits D2 and D3 is at the base of a prominent oyster coquina with *Nummulites*; and that between Subunits D3 and D4 is marked by a bioclastic limestone with oysters and operculines. “Lucinids” (*Tellina thebaica*) are abundant at ~ 171 m and at 175 m at the base and top of Subunit D1, respectively, and between 183.5 m and 185 m and 186 m in Subunit D3.

Unit E (Fig. 8d)

Thickness: 9.6 m (190.2–199.8 m).

Lithology: It consists of nodular limestone without flints, generally forming a semi-vertical face. It is referred to as “Nodular Limestone E” [NLE]. Nodules are ~10 cm in diameter. A thin limestone bed (Subunit E2, 195.80–196.55 m) with turritellid moulds occurs within the NLE (Fig. 8d). The lower part of Subunit E1 (190.2–192 m) contains scarce oyster shells and operculines.

Lower boundary: It is marked by two successive bioclastic limestone beds with abundant shell debris.
Upper boundary: It is a bioturbated surface at 199.8 m.
Remarks: This unit is well exposed on the West Bank and forms the top of Cliff 3.

Unit F (Fig. 8d)
Thickness: 6.9 m (199.8–206.7 m).
Lithology: This unit consists of massive intervals of limestone with intercalated marls (Fig. 9b). Subunit F1 is a prominent, compact limestone without clear stratification and with large flints arranged parallel to the bedding in its lower part. Subunit F3 is also a limestone but softer and without flints, except in its upper part which is a more indurated bioclastic limestone with oysters and operculines. Subunit F5 is a well stratified bioclastic limestone with scarce operculines. Subunits F1 and F3 are separated by a ~1 m thick green to variegated marl (Subunit F2; 201.60–202.60 m;) whereas Subunits 3 and 5 are separated by a 90 cm thick purple marl (Subunit F4; 204.70–205.60 m). The base and top of Subunit F2 are bioturbated. The base of Subunit F4 is also bioturbated and its top is transitional.
Lower boundary: This is a bioturbated surface at 199.8 m.
Upper boundary: This is the contact between the bioclastic limestone of Subunit F5 and the nodular limestone of Unit G.
Remarks: Unit F forms the basal part of Cliff 4 and is often concealed by screes; however, its thick and resistant Subunit F1 is often visible and forms a distinctive landmark above Cliff 3.

Unit G (Fig. 8d).
Thickness: 5.90 m (206.7–212.6 m).
Lithology: This is a moderately thick interval of nodular limestone with two levels (207.6 and 209 m) of flints near the base and one (212.6 m) at its top. Nodules are relatively small (a few cm in diameter). A thin interval of stratified limestone occurs at 207.40 m. It is the third of the five distinctive nodular limestone units and we refer to it as "Nodular Limestone G (NLG in Fig. 8d).
Lower boundary: It is the contact between the bioclastic limestone of Subunit F5 and the nodular limestone of Unit G.
Upper boundary: It is marked by the thin layer of flints at 212.6 m below a limestone rich in ~10 cm diameter, carbonate concretions (Unit H).

Unit H (Fig. 8d)

Thickness: 22.8 m (212.6–235.4 m).

Lithology: This unit is comprised of soft and hard, concretion-poor and flint-rich limestone. Flints are of highly diversified size, morphology and arrangements. Siliceous limestone also occurs. A single interval of yellow marl is present.

Subunit H1 consists of a vertical succession of a) cm-scale alternating hard and soft limestone (212.6–215.6 m), with a 1 m thick bed of hard calcareous concretions at the base (212.6–213.6 m), a single layer of large flints near the top (215 m) and a bioturbated surface at 215.6 m; b) homogenous limestone (215.6-218.8 m) which is bioclastic at the base (215.6–215.9 m) and with sparse operculines and scarce small flints at the top (218.0-218.80 m); c) alternating layered siliceous limestone and layered tabular to subtabular flints (218.8–221.0 m). The upper part of this interval is marked by a 5 cm-thick tabular flint (~ 220.3 m); and d) concretions/concretionary layers of siliceous limestone with flint cores (221-224.6 m). Small, irregular flints in limestone lacking concretions mark the base of this interval (211.00-221.5 m).

Subunit H2 consists of 1.20 m of essentially yellow marls (Fig. 9c). Light purple marls (224.7–224.9) rest on a thin (~10 cm) limestone bed at the contact with the concretionary layers of Subunit H1. They are overlain by variegated marls that contain at the base a thin layer of carbonated concretions (ankerite). This is followed by a distinctive interval (225.1-225.9) of homogenous yellow marls. Subunit H3 consists of soft limestone with thin subtabular flint layers and occasional, rather large (5-10 cm in diameter), subspherical flints (Fig. 9c).

Lower boundary: It is marked by the thin layer of flints at 212.6 m below a limestone rich in carbonate concretions (Subunit H1).

Upper boundary: It is marked by a bioturbated surface at the top of Subunit H3.

Remarks: Unit H is well exposed in Gebel Gurnah. Subunit H2 is particularly well exposed in the hills of Sheik Abdel Gurnah near Tomb TT91 (Fig. 9c)

Unit I (Fig. 8e).

Thickness: 36.8 m (235.4–272.2 m).

Lithology: This unit is comprised of soft and hard, sometimes concretionary, stratified limestone (Fig. 9d). Siliceous limestone may occur as well. Unit I is rich in flints, Like Unit H, but only in its lower part (Subunit I1; 235.4-257.9 m) and it is richer in tabular flints. Additionally Unit I is rich in bioclastic beds and bioturbated surfaces are common.

Subunit I1 (235.4–257.9 m) consists of a vertical succession of a) concretionary limestone (235.4–244 m) with episodic levels of flints (Subunit I1a). Some flints are very large and lie in the bedding plane (notably at 235.9, 238.20, 244.4 m). Small, subspherical flints occur between

238 and 240 m. Large and sporadic flints occur around 240.5 and 244.3 m; b) finely stratified limestone with prominent beds of siliceous limestone (Subunit I1b; 244–250.3 m). In addition, this interval is characterized by the occurrence of only tabular and subtabular flints; and c) concretionary limestone (Subunit I1c; 250.5–257.9 m). The concretions are siliceous and sparse. The flints are rarer than below, in some instances small and scarce (250.5–252 m; 256.5 m), in other cases large and in the bedding plane (253.50 and 254.10 m).

Characteristic subtabular flint occur between 236 and 238 m in Subunit I1; tabular, cm-thick flints occur also, in particular at 235.5, 246.7, 249.8, 250.25 (which forms a double layer) and 252.10 m. Prominent bioclastic horizons occur at 238.50, 240.40, 243.80, 244.70, 251.20, 253.9 m. Prominent bioturbated surfaces were noted at 235.4, 240.10, 243.7 and 253.9 m. In addition, *Nummulites* are sparse at 253.9 m.

Subunit I2 (257.9–272.2) consists of stratified and weakly stratified limestone without flints. Its base between 257.9–258.80 m is marked by three bioclastic intervals, each with a bioturbated basal surface. Its upper part (269.5–272.20 m) is marked by a succession of layers of hard limestone, changing upwards from thin (~10 cm) to thicker (~20 cm) and with nodules. Subunit I2 is naturally divided into two subunits. Subunit I2a consists up to 264.4 m of numerous thin layers of hard limestone with two bioclastic levels, one (259.50 m) with operculines and the other (264.40 m) with *Nummulites* and oysters. Subunit I2b is a mostly homogenous, weakly stratified limestone passing upwards into thin, indurated layers.

Lower boundary: It is marked by a bioturbated surface at the top of Subunit H3.

Upper boundary: It is marked by a short succession (over 1.20 m) of layers of hard limestone, that change upwards from thin (~10 cm) to thicker (~20 cm) and with nodules.

Remarks: This unit is well exposed in the cliffs of Gebel Gurnah.

Unit J (Fig. 8e)

Thickness: 17.8 m (272.2–290 m).

Lithology: This is a thick and homogenous unit of nodular limestone, referred to as “Nodular Limestone J” [NLJ]. It forms a prominent vertical cliff that is readily recognizable in the landscape and in aerial photographs. The presence of turritellids between 272.80–273 m is notable. A 2 meter thick distinctive bed (273–275 m) containing sporadic large flints and resulting from the hardening of the nodules, marks the lower part of Unit J and may serve for local/regional correlation.

Lower boundary: It is marked by a rapid upwards change from thin (~10 cm) to thicker (~20 cm) layers of hard limestone to layers of hard limestone with nodules over an interval of 1.20 m (Fig. 9d).
Upper boundary: This is the top of LNJ; it is also locally highlighted by the presence of a >5 cm layer of tabular flint.
Remarks: Unit J, which forms the face of Cliff 4, is remarkably well exposed on the West Bank. The 2 m-thick distinctive bed (273–275 m) close to the base of the unit is particular well exposed at Sheikh Abdel Gurnah.

Unit K (Figs. 8e, f).
Thickness: 23.30 m (290–313.3 m).
Lithology: Stratified limestone with flints, bioclastic levels and intercalations of nodular limestone and some calcareous concretions. It consists of a vertical succession of a) stratified limestone with, in the upper part (290–294.95 m), tightly stacked intercalations of thin (<10 cm) beds of hard limestone. Two levels of flints immediately underlie these thin beds whereas a layer with scarce flints overlies them; b) stratified limestone with sparsely distributed intercalations of thin (<10 cm) beds of hard limestone (294.95–305.50 m). Two thick (~ 40 to 50 cm) bioclastic beds with flints occur at ~296.10 and 299.30 m. Flints also occur sparsely, most notably in (sub)tabular layers at 303.80 and 305.20 m; and c) nodular limestone (305.50–306.9 m) followed by stratified limestone with nodules (up to 310.10) followed by nodular limestone (up to 311.10 m), followed by stratified limestone without nodules (up to 313.3 m). A tabular flint occurs at 309.80 m.
Unit K differs from the underlying units in the common occurrence of macrofossils. It is characterized by the LO of *Spondylus* (frequent) and *Turkostrea*, but other molluscs are also found including turritellids and *Plicatula*. *Nummulites* are present as well. Prominent omission surfaces occur at 296.10, 299.10 and 311.10 m.
Lower boundary: It is the top of NLJ which is often highlighted by the presence of a >5 cm layer of tabular flint.
Upper boundary: It is the contact between the stratified limestone without nodules and the nodular limestone of Unit L (NLN).
Remarks: : Unit K, which forms the major part of Cliff 5, is rather poorly exposed immediately below EL Qurn (section ELQB). It was logged mainly in the section ELQC to the west (Fig. 5).

Unit L (Fig. 8f)

Thickness: 12.7 m (313.3–326 m)
Lithology: Dominantly nodular limestone referred to as “Nodular Limestone L” (NLL), with few intercalations of thin, platy limestone beds in the lower part (313.30–320 m) and thicker, stratified limestone with scarce flints and bioclastic limestone (at 321.4 and 323.5 m) in its upper part. A bioturbated surface occurs at ~323.5 m. Macrofossils, including turritellids and other gastropods as well as oysters (in particular *Turkostrea*) are common. No *Nummulites* were recovered.
Lower boundary: It is the contact between the stratified limestone without nodules of Unit K and the NLN.
Upper boundary: It is the contact between the NLN and the laminated limestone of Unit M.
Remarks: Unit L, which lies in the upper third of Cliff 5, is well exposed at Gebel Gurnah.

Unit M (Fig. 8f).
Thickness: 12.60 m (326–338.60 m).
Lithology: Stratified limestone with intercalated bioclastic limestone and thick *Turkostrea* coquinas. Thin laminated limestone also occurs (at 326.10 and 330–330.20 m). A bioclastic limestone between 328 and 329.10 m contains *Turkostrea* and gastropods (although no turritellids). A massive, 2.6 m thick coquina between 330.9 and 333.5 m contains exclusively *Turkostrea*. Other coquinas occur at 335–336 m and 337.60–337.70 m. Operculines were recovered at 338.50 m**.** Scarce but large (up to 50 cm) and subspherical flints occur at 327.6 and 333.20 m. Horizontally elongated nodules mark the lowermost part of the unit. Omission surfaces occur at 327.95 and 336 m.
Lower boundary: It is the contact between the NLN and the laminated limestone of Unit M.
Upper boundary: It is the top of the section at El Qurn.
Remarks: The thick oyster (*Turkostrea*) coquina forms a prominent ledge near the top of Cliff 5. A further 5 to 6 m of limestones are exposed at higher levels further east, but the original lithology has been overprinted by weathering processes, including recrystallisation (and ?silicification), and it is difficult to identify. This unit is exposed only locally at the top of the cliffs.

IV-b- Lithologic markers.

The lithology of the Thebes Formation in the Gebel Gurnah section is highly repetitive, except for the lower 93 m (lithologic Unit A) that consist of homogenous, fine-grained limestone, and the upper 8 m (lithologic Unit M) that are formed of a succession of *Turkostrea* coquinas. However, distinctive lithologies characterize specific levels/intervals in the local succession which, from our preliminary fieldwork, are likely to be useful for regional correlation and geological mapping (Fig. 11). We recognize four marker lithologies: 1) nodular limestone, 2) marls, 3) characteristic limestone facies, and 4) specific flints and their distribution patterns in the calcareous matrix.

IV-b-1. Nodular limestone: This may be the most remarkable lithology in the formation. Nodular limestone forms five thick packages occurring in Units A, E, G, J, and L after which they are named, and contributes to the most prominent geomorphologic features in the Theban landscape: nodular limestone forms the upper part of each of the five Theban cliffs except Cliff 2 (Dupuis et al., 2011). The five packages differ notably from one another, thus constituting reliable means of correlation.

a- NLA (~13 m) differs from all others by its large (>20 cm), elongated nodules arranged parallel to stratification and causing a distinctive wavy pattern. A ~50 cm-thick phosphatic limestone (Subunit B1) overlies NLA forming the very top of Cliff 1. NLA and Subunit B1 are separated by a bioturbated surface.

b- NLE (9.5 m-thick) and NLG (6.5 m-thick; Fig. 9b) are very similar to each other, with nodules comprised between 5 and 10 cm although the nodules are generally larger in NLG. NLE contains operculines and oysters at the base and turritellids in a fine-grained limestone at mid-height. The lower part of NLG contains flints.

c- NLJ (20 m-thick) contains turritellids in its lower 50 cm, above which it is more indurated (cemented) over ~ 2 m.

d- NLL (13.5 m-thick) is characterized by thin (10 cm to 1 m) intercalations of platy limestone beds, biodetritic limestone eventually with oysters (*Turkostrea*), gastropods (turritellids in particular). NLL forms Cliff 5.

IV-b-2. Other limestones: Slight but characteristic lithologic variations (Figs. 10a-e) may help in determining location in this thick limestone succession that the Thebes Formation represents, and also help confirm identification of the NL packages away from the Theban cliffs and in particular in the Theban tilted blocks. Main examples of

a- Beds of indurated concretionary limestone underlie NLA between 86.9–92 m and NLJ between 271.9–272.2 m, and overly NLG between 212.6 and 213.6 m.

b- Layers of concretion-bearing limestone and massive concretionary limestone are present in Unit D (171.8–174.8 m; 176.9–180.6 m), Unit H and Unit I (221.8–224.6 m, 236.3–237.8 m, 240.9–243 m, 255.5–259.3 m).

c- Thin, indurated layers are distinctive markers in otherwise monotonous successions of flint-bearing limestone. In this respect, two such layers (at ~57.8 m) in Subunit A4 form a useful reference level. Similar layers of indurated or silicified limestone are stacked at the base of Unit H (between 214.6 and 215.2 m), in Subunit I1 (between 245.3–249.5 m), in Subunit J2 (260–264 m) and near the base of Unit K (292.10–295 m).

d- Bioclastic limestones, most of them resting on a bioturbated surface, are common in lithologic Unit D (between 175.4–176.2 m, 181.8–182.5 m and at 186.3 m) and serve to differentiate subunits.

e- In Unit M the concretionary limestones are rich in shells of *Turkostrea* and pass upwards into coquinas (331.3–333.5 m, 335.1–336 m).

IV-b-3. Marls: Seven marly intervals constitute reliable lithologic markers. Their thickness varies considerably, in particular because of tectonic deformation. They are:

a- The 1 m thick, pink to violet marl of Subunit B2a (94–95.20 m), which rests on the ledge of Cliff 1 forming a marked notch below Subunit B2b.

b- The violet marl (110.5–111.5 m; Fig. 8b) of Subunit B5 that lies between two bioturbated surfaces, sandwiched between the underlying *Anondotia*-bearing limestone of Unit B4 and an overlying white limestone without flint.

c- The variegated marl (132.5–134.3 m; Fig.8c) of Subunit C1, which is comprised between a 1 m thick limestone with a double layer of flint, below, and, above, two thin beds of indurated limestone with rare *Anondotia* and turritellids.

d- The pink marl (141–141.95 m; Figs. 8c, 9a) of Subunit C3, that overlies a white limestone from which it is separated by a bioturbated surface, and underlies a bioclastic limestone with turritellids.

e- The green and variegated marl (201.60–202.60 m; Figs. 6d, 9b) of Subunit F2 overlies a bioturbated surface at the top of Subunit F1, which is a flint-rich limestone at the top of Cliff 3.

f- The ~1 m-thick purple marl of Subunit F4 (204.70–205.60 m), that rests in bioturbated contacts with underlying and overlying bioclastic limestone.

g- The yellow marl (224.60–225.8 m; Figs. 6d, 9c) of Subunit H2, which is transitional with the underlying limestone and in sharp contact with the overlying limestone.

Two additional distinctive marly lithologies occur at Gebel Gurnah. One is the chalky marl (4–4.80 m) of Subunit A2 that forms a notch above the ledge of Unit A1. The other is a 9.50 m-thick ankeritic claystone of Subunit B3b (98–107.10 m), which forms the base of Cliff 2.

IV-b-4. Flints: Flints are very abundant and of diverse size and shape (Fig.10f-h) in the Thebes Formation at Gebel Gurnah although they may be very rare (e.g., in the nodular limestone) or totally absent (e.g., Unit I, 257.9–272.2) in some intervals. Flint-bearing limestones in Subunits B6 (111.5–131.5 m), C4a (141.95–154 m), D2 and D3 (175.4–186.3 m) are prominent and reliably help in local correlations. Characteristically, Subunit B6 contains large flints in bedding planes whereas the homogenous limestone of Subunit C4a contains dispersed, small, marble-like flints. Layers of concretions are intercalated with semi-tabular flints in Subunit D2, whereas flint forms the nucleus of concretions in Subunit D3.

IV-c- Paleontological Markers: The sporadic/irregular distribution of different paleontological groups in the Thebes Formation helps also in lithologic determination and correlations (Fig. 12).

Macrofossils may be very abundant and form bioclastic limestone and coquinas or they may be absent as for instance in the greater part of Unit A:

a- With the exception of a recently observed specimen in Subunit A1 at Sheikh Abdel Gurnah, the LO of *Lucina thebaica* is at 81.5 m above the Esna Shale Formation (base of Subunit A4) and it becomes more abundant in Subunit A5. This species does not occur above Unit D (above 186 m). It is abundant in Subunits B4 (~108.5 m), and C4 (147–156 m; associated with venericardids), and at the base of Unit D (at ~171 m, 175 m, and between 183.50 and186 m).

b- Spondylids and plicatulids are abundant only at some levels in Unit K between 293 and 297.5 m.

c- Smooth oysters occur discontinuously from Unit C to the top of the section. They are mostly present in bioclastic limestone, notably at ~170 m, ~182 m, ~186.50 m, ~204.5 m, ~243.8 m, ~258 m, ~296.50 m, ~324 m, ~328.5 m, 331.3 to 333.5 m, and 335.50 to 337.30 m.

d- *Turkostrea* occurs as well above 293.50 m in Unit K.

e- Turritellids also exhibit an irregular distribution between 135.8 m in Subunit C2 and 324 m in Subunit L. It would appear that they are more common above 296.5 m in Subunit K. Except at 140 m (Subunit C2) where they are present together with crabs and echinoids, other gastropods are present only above 296.5 m (Subunit K).

Among benthic microfossils, larger foraminifera are dispersed. *Nummulites* appear in Subunit C4, ranging between 165 m and 310 m at the top Unit K. They often occur in bioclastic limestone as at 170 m (base of Unit D), 158 (base Unit I) and 209.5 m (in Unit K). Operculines appear in Unit D at 186.5 m and range up to the top of the section.

V- Depositional environment of the Thebes Formation at Gebel Gurnah and depositional sequences

As shown above, the lithologic succession of the Thebes Formation at Gebel Gurnah is highly repetitive. It is comprised of a small number of lithologies that occur in repeated, more or less complete successions, each lithology being indicative of a specific paleoenvironment. This repetition is, from base to top, Marl – Fine-Grained Limestone – Bioclastic Limestone – indurated and concretionary limestone – Nodular Limestone. To a lesser degree it also includes coquinas and phosphatic limestone. The six lithofacies of the formation and their paleoenvironmental significance are discussed below together with paleontological evidence that supports this interpretation. The distribution of specific groups of macro- and microfossils provides paleobathymetric information. In turn, this discussion forms the framework for the delineation of six depositional sequences in the Thebes Formation at Gebel Gurnah.

V-A- Depositional environment

V-A-1 Lithofacies (Figs.8a-f)

<u>Marl</u>

The seven, thin, marly units that occur in the formation are described above. They are often very indurated and may be laminated. This lithofacies has the highest terrigenous component in the section.

Depositional environment: The marls in Units A and B have relatively high proportions of planktonic foraminifera. Benthic foraminiferal assemblages are difficult to evaluate due to the generally poor preservation. The best-preserved assemblage, from Unit B2, includes outer neritic taxa (such as *Bulimina aksuatica* and *Vaginulinopsis* ex gr. *decorata*; 100 to 200 m water depth). The marly units tend to occur at or close to the base of the shallowing-upwards sequences (see below), suggesting that they may be the deepest-water facies.

<u>Fine-grained limestone</u>

The dominant lithology in the section is characteristically light gray to white, homogenous and blocky in fresh exposures, but weathering at the surface into 'paper-shales' with a pseudolaminated texture. Lamination and thin-bedding have been cited in this facies in a number of publications, including Snavely et al. (1979), but these are weathering effects, reflecting expansion of horizontally-oriented clay minerals during repeated wetting and drying cycles. This facies is inferred to be essentially composed of coccoliths, and this can be confirmed in some intervals (e.g. Tawfik et al., 2010, fig. 5c: Unit A; MPA, pers. obs. in smear slides), but partial recrystallization, perhaps related to the formation of ankerite, has degraded or destroyed much of this fabric (Shaaban, 2004). Petrographically this facies comprises mudstones and wackestones. Dispersed whole or fragmented benthic and planktonic foraminiferal tests comprise the majority of the bioclasts.

The 'paper-shale' weathering reflects the relatively high proportion of clay minerals, particularly in Unit A which contains at least as much as 30% clay minerals at some levels (see below; see also Tawfik et al., 2010, table 1).

Depositional environment: The relatively high proportion of planktonic foraminifera in some intervals, the rarity of molluscs or echinoids, the general absence of coarse bioclastic debris and of primary sedimentary structures probably indicate deposition in outer neritic (100–200 m) environments. The benthic foraminiferal assemblage, although generally poorly preserved, includes *Bulimina aksuatica*. Radiolaria are present in Unit A, which is probably the deepest lithologic unit of the formation (see Tawfik et al. 2010, fig. 7c). Snavely et al. (1979) suggested bathyal depths, but this interpretation is not supported by the benthic foraminiferal assemblages.

Bioclastic limestone

Lithology: These include micritic and microsparitic limestone (mainly wackestone), with varying proportions of bioclasts, dominantly calcitic molluscs (essentially oysters), calcitic mollusc debris and (in some beds) larger foraminifera (*Nummulites* and *Operculina*) (e.g. Tawfik et al. 2010, fig. 6c). Dispersed quartz grains were noted in thin sections by Tawfik et al. (2010). This facies is generally homogenous (thoroughly bioturbated), but diffuse thalassinoid burrows may be identifiable where filled by concentrations of bioclastic debris. Fining-upwards trends in the bioclasts can be recognized in some thicker units (e.g., Unit E1a).

Distribution: This facies occurs as thin beds, typically < 2 m thick, mainly through the middle of the section. Approximately 12 of these beds have been identified; the lowest significant unit is at 170 m, and the highest at 264.4 m. Due to their relative induration compared to adjacent limestones, they tend to weather out as projecting/overhanging ledges, some of which can be useful topographic markers, as noted above.

Relationships: These beds occur predominantly within the fine-grained limestone. They mostly have an interburrowed base, with very shallow thalassinoid burrows, and a transitional upper boundary.

Depositional environment: These units have previously been interpreted as storm-generated units, 'nummulite tempestite banks' (Keheila and El-Ayyat 1990). There is, however, no evidence of high-energy conditions during their deposition; they have no internal sedimentary structures (lamination, layering or HCS [hummocky cross-stratification]), and exhibit only very limited fining-upwards trends. The basal thalassinoid-burrowed omission surfaces indicate that deposition was preceded by a break in sedimentation, and their high level of bioturbation indicates slow rather than rapid sedimentation. No evidence of erosion was seen. The occurrence of larger foraminifera, large oysters and other molluscs indicates sedimentation within the photic zone at relatively reduced rates. The bioclastic limestone beds occur generally within the middle part of the larger shallowing-upwards sequences (see below) and do not mark significant facies boundaries. These characteristics indicate that they probably reflect minor sea-level fluctuations and that the basal omission surface is a parasequence boundary, with the bioclastic beds reflecting initial decrease in sediment supply during sea-level rise.

<u>Indurated and concretions/concretionary limestones</u>

These limestones occur as layers of ovoid/oblong concretions or thin wavy tabular layers, with more or less diffuse boundaries. This facies is represented within Units A (Subunit A5; Fig. 8b), D (Subunit D1; Fig. 8c), H (Subunit H1, lower part between 212.6 and 213.5 m, and upper part between 221.8 and 224.6 m; Fig. 8d), I (lower part between 236.3 and 237.8 m, and upper part between 250.7 and 257.4 m; Fig. 8d and 8e, respectively), K (between 307.3 and 308.7 m; Fig. 8e) and M (lower part ~ 327 m; Fig. 8f). It generally forms thin units some 2 or 3 m thick. This facies generally overlies and is transitional to soft limestones. In some intervals it occurs interbedded with soft limestones, forming distinct layers of concretions or diffuse thin indurated beds.

Depositional environment: Microfaunal characteristics have not been studied due to induration. The occurrence of dispersed shell debris and *Nummulites* in some intervals suggests a shallower environment than for the fine-grained limestone, probably mid-neritic (30–100 m).

<u>Nodular limestone</u>

The nodular limestone constitutes a prominent lithology in the Thebes Limestone at Gebel Gurnah (see above). In this hard micritic limestone with a 'nodular' texture, the softer matrix can be recognized between the remnants of thalassinoid burrow networks. Fine bioclastic debris is common. The units of this facies have variably developed transitional bases and sharp tops. Units A5, E and J each form the culmination of vertical trends in decrease in mud content and increase in induration, interpreted as shallowing (see below).

Depositional environment: The bioclastic debris, including larger foraminifera, and the occurrence of beds of turritellid gastropods in NLE and NLJ, indicate relatively shallow water depth, probably inner neritic (0–30 m). Nodular chalks are well documented in the Upper Cretaceous of NW Europe. They were interpreted by Kennedy and Garrison (1975) and Gale (1996) as due to selective early diagenetic cementation and lithification at shallow depth below the sea floor, during pauses in sedimentation. In these areas they are often overlain by erosion surfaces/hardgrounds, interpreted as formed during the most rapid phases of sea-level fall. This accords closely with the context of the nodular limestone entities at Gebel Gurnah. Although hardgrounds are not developed, their upper boundary marks a change to probably deeper-water facies, and in the case of Unit A5, is followed by a phosphatic limestone. We interpret the nodular limestones as the culmination of shallowing in the sequences in which they occur.

<u>Coquinas and phosphate limestones</u>

Several bioclastic layers yielding oyster shells as dominant constituent may be designated as coquina. One is located in Unit D at 181.8 m (Fig. 8c). Two others are restricted in Unit M between 331.3 and 333.5 m and at about 335.5 m (Fig. 8f). Both may result from the winnowing of the fine fraction on the sea floor and suggest possible storm or long-shore current effects. Nevertheless the scarcity of such kind of current evidence is noted. Their diverse contents probably relate to slightly different environments. The coquina of Unit D made of un-ribbed oysters and *Nummulites* probably indicate a mid-neritic environment. By contrast, the accumulation of ribbed oysters *Turkostrea* in the coquinas of Unit M may point to a shallower inner neritic (0-30 m) environment. Both are prominent landmarks.

Calcium phosphate was only identified as a significant constituent in Subunit B1 overlying NLA at the very top of Cliff 1 due to a deeply bioturbated surface (Fig. 8b). This indurated limestone is crowded with brown grains (of mm to cm size) and phosphate coated limestone pebbles. Phosphatic grains and coated pebbles are typical constituents of transgressive lags. This is consistent with the depositional interpretation (see below).

V-A-2 Paleontologic indicators of paleobathymetry

The depositional environment of the Thebes Formation may be inferred from the nature of the macro- and microfossils that occur in it (Figs. 12, 13).

Molluscs

As elsewhere in the Thebes formation, only calcitic molluscs (mainly ostreids) have the shell preserved; others are represented in the more indurated lithologies by external moulds, or in soft limestone by distorted and often compressed limonitic casts. This account deals only with molluscs recorded during logging; a more extensive search was not carried out. Molluscs are very rare through most of Unit A. The large lucinid bivalve *Anondotia* occurs in four discrete intervals (in Units A to D) where they consist of bivalved specimens, often in growth-orientation (Fig. 8). These are 1) the upper part of Subunits A4 and A5; 2) the upper part of Subunit B3b, base of Subunit B4 and base and top of Subunit B6; 3) Subunits C2 and C4; and 4) Subunits D1 and D3). At the species level, *Anondotia hatshepsutae* occurs in the upper part of Unit A4 and the lower part of Unit A5. *Anondotia* [*Lucina*] *thebaica* appears in the upper part of Unit C, and again in the upper part of Unit D. (We rely here on the generic names used by previous authors, aware that "*Anondotia*" may not be the appropriate genus name to be used here). *Anondotia thebaica* is a characteristic species of the middle Thebes Formation over a wide area. El-Naggar (1966 and later publications) recognized a '*Lucina thebaica* Zone' in sections in the Nile Valley, and it occurs in a comparable interval in the Kharga Oasis (CK, personal observations). Its distribution is, however, environmentally controlled, and it cannot be used as a chronostratigraphic marker. Lucinids are chemosymbiotic (Taylor and Glover, 2000), and can live in nutrient-poor environments. Their preservation as bivalved individuals reflects their deep infaunal habitat. Their occurrence in diffuse layers in the upper part of Unit D probably reflects fluctuating sedimentation rates.

Epifaunal molluscs appear at the base of Unit C, represented by unribbed (smooth) oysters. These are abundant in some bioclastic limestone beds in the middle Thebes Formation, forming thin ostreid coquinas in Unit C and Unit H. The morphology of these ostreids (*Pycnodonta*?) indicates deeper water (down to mid-neritic depths) than ribbed taxa; their occurrence reflects episodic reduction in sedimentation rates. Turritellid gastropods are common in several bioclastic limestone beds, and also in thin beds within the nodular limestone Units E and J. Turritellids are epifaunal and semi-infaunal opportunistic suspension-feeders, which tend to occur in large numbers as they are able to exploit high-nutrient environments. They indicate a probable inner neritic environment.

More diverse mollusc assemblages occur primarily in the upper Thebes Formation (Unit K). These include the partly calcitic taxa *Spondylus* and *Plicatula*; other genera are represented by moulds. Extensive lists of molluscs given by Cuvillier (1930) are mainly from this interval. These indicate inner neritic environments (0–30 m). The first ribbed oysters (*Turkostrea* gr. *multicostata*) are rare near the base of Unit K, and become common in the bioclastic limestone beds of the upper part of Unit K. These are definitely an inner neritic group. The base of Unit L is formed by a thick *Turkostrea* coquina, and several *Turkostrea* beds occur in Unit M (Fig. 12).

<u>Smaller benthic foraminifera</u>

Specific assignment is often uncertain. Many samples were barren or yielded only indeterminate specimens. Diversity is relatively low, except in marl or marly chalk intervals (Units A1, A2, B2). This may be biased by the fact that these are the best preserved assemblages. Overall, there appears to be a general upward reduction in diversity, with only two species identified in most samples from Units H and K. In Units A, B and C, *Bulimina*, *Cibicidoides*, *Heterolepa* and *Lenticulina* are the most common genera. *Loxostomoides applinae* was recorded in Unit A2. *Bulimina aksuatica* occurs consistently in productive samples from Units A2 to B6, and is the dominant taxon between Units A2 and B2. *Bulimina* aff. *midwayensis* is represented in Unit B2. Occasional specimens of *Vaginulinopsis* ex gr. *decorata* are recorded in Units B2 and B5. The overall assemblage through Units A1 to C3 is of 'Midway-type' (Berggren and Aubert, 1975; Van Morkhoven et al., 1986), indicating outer neritic water depths (100-200 m) for much of this interval.

From Unit B6 to C2 sparse low-diversity assemblages, in which *Baggina* and *Cibicidoides* occur consistently, suggest somewhat shallower depths, probably mid-neritic (30–100 m). Unit C4 has a distinctive assemblage, dominated by miliolids, *Eponides* and *Textularia,* suggesting an inner or mid-neritic environment. Foraminifera in Unit D are mostly sparse and indeterminate. No samples were analyzed from the indurated Unit E. Unit F has a very sparse assemblage, dominated by *Cibicidoides*. Units G and J are also indurated, and were not analyzed. In Units H and K, a very low diversity assemblage is dominated by *Hanzawaia*? and *Nonionella*, with *Baggina* a significant constituent at some levels in Unit H. These suggest a restricted, mid- or inner neritic environment.

<u>Larger benthic foraminifera</u>

Larger benthic foraminifera (LBF) are restricted to the middle and upper Thebes Formation (mainly Units D to M). They comprise mainly *Operculina* and small *Nummulites*, which are abundant in some units, with rarer *Assilina*. The lowest record is at ~165 m (near the top of Unit C). They are mainly represented in the bioclastic and the nodular limestones which are interpreted as the shallowest lithofacies. A more substantive discussion on the large benthic foraminifera may be found in Appendix 3.

V-A-3. Discussion

Depositional sedimentary structures are almost entirely absent in the section. The only examples noted are lamination in several thin beds in the highest part of Unit K (~ 313 m; Fig. 8f). The overall context of the Gebel Gurnah section suggests location on a very wide shelf probably at least 100 km from the coastline. The influence of any local or regional tectonics is essentially unknown and undetected. In this context, the vertical alternation of lithofacies can be most parsimoniously interpreted as resulting from fluctuations in water depth.

Keheila and El-Ayyat (1990) and Keheila et al. (1991) presented a detailed interpretation of the depositional environment of the Thebes and Drunka Formations in the Nile Valley and adjacent areas between Qena and Sohag. Their main conclusions were that 1) the Thebes Formation was deposited in a "tidal flat environment with semi-restricted water circulation, and tempestite Nummulites bank environment" (Keheila et al. 1991, p. 155). The Drunka Formation was interpreted as deposited in "an open shelf lagoon of restricted circulation, with well washed and winnowed bar facies at its uppermost part" (Keheila et al. 1991, p. 156); 2) abundant reworked Paleocene planktonic foraminifera in the lower part of the Thebes Formation indicate extensive uplift and erosion of the underlying Esna Formation; and 3) the Drunka Formation and Thebes Formation are laterally equivalent and interfingering units. This aspect of the interpretation has been discussed above.

One may inquire why the interpretation of the Thebes Formation outcropping between Qena and Sohag is so markedly different from the present interpretation of the Gebel Gurnah section, where the succession is apparently very similar. The interpretation of the fine-grained limestone and indurated limestones as intertidal was based essentially on four criteria (Keheila and El-Ayyat 1990): 1) thin lamination, 2) dolomitisation, 3) presence of authigenic evaporitic minerals (gypsum, anhydrite and halite) and 4) "Vertical or inclined bioturbation, which is repeated several times" (*op. cit.*, p. 35). The apparent lamination of the soft limestones of the Thebes

Formation has misled previous workers, and is a weathering effect, as noted above. In fresh (unweathered) exposures these sediments are invariably blocky and homogenous (unbedded). Dolomite is a significant constituent almost throughout the Thebes Formation at Gebel Gurnah (Fig. 14; Tawfik et al., 2010; in fact ankerite, rather than dolomite, is present in the Thebes Limestone, see below), irrespective of depositional environments, as noted above. Authigenic evaporitic mineral constituents have been documented at a number of sites in the Thebes Formation, including Gebel Gurnah (Wüst and Schluter, 2000, i. al.). They are generally considered secondary minerals, linked to pyrite weathering and precipitated from percolating groundwater. Finally, reference to repeated “vertical or inclined bioturbation” presumably refers to interburrowed omission surfaces, which are characteristic of marine environments. The ichnofossil(s) represented were not specified.

Planktonic foraminifera, which are present in variable proportions, particularly in the lower Thebes Formation (Keheila et al. 1991, figs. 8, 9), were interpreted by these authors as reworked from the underlying Esna Shale Formation, apparently on the basis of their incompatibility with the tidal flat interpretation. Keheila and El-Ayyat (1990, p. 37) stated that reworking was indicated by 1) “Concentration [...] in scattered limited lenses”. This apparently refers to their high abundance in specific *beds* (see Keheila and El-Ayyat 1990, figs. 3, 4); the lens-like character of these beds was inferred rather than directly observed; 2) relatively poor preservation and fragmentation. Poor preservation is characteristic of the foraminifera in the Thebes Formation, due largely to the encrusting chalk. Fragmentation [not universal, judging by their illustrations] is not necessarily a result of reworking but can result from a variety of factors; and 3) filling of foraminiferal chambers by coarse-grained calcite, silica or other minerals not represented in the matrix. Again this does not necessarily indicate reworking, simply post-depositional filling of voids. The identification of various Paleocene planktonic taxa cannot be confirmed from the published illustrations (Keheila et al., 1990, p. 153, fig. 1; Keheila et al. 1991, fig. 14). Careful inspection and evaluation of these illustrations show that none of the specimens have been correctly identified (Table 4); they have nothing to do with Paleocene planktonic foraminifera and do not support the contention that they represent reworking into the Lower Eocene Thebes limestones. Indigenous planktonic foraminifera are common in the lower Thebes Formation at Gebel Gurnah and other sites, and there is no reason to believe that the situation is any different in the Qena-Sohag area. In addition, there is no evidence for a (postulated) pre-Thebes Formation uplift and erosion of the Dakhla Formation (the presumed source of the planktonic foraminifera) there. In the Gebel Qreiya section (Wadi Qena), a complete section of the upper Esna Formation up to Zone P7 (early Ypresian) is represented (Berggren and Ouda 2003b). We conclude that there is no evidence for intertidal environments in the Qena-Sohag area, and that the overall succession and overall depositional environmental trends are probably similar to those in Gebel Gurnah and other Thebes Formation sections further south.

V-B- Depositional sequences

From the evidence provided by lithofacies and paleontology, it is clear that the lithologic succession in the Thebes Formation corresponds to six main sequences. For reasons that will be apparent as our discussion progresses, they are labeled here, in stratigraphic order: Thebes 1 to Thebes 5 and Minia 1 (Fig. 15). The succession of marl and marly limestone to fine limestone forms the Transgressive System Tract (TST), whereas the succession of fine limestone to limestone with concretionary beds and bioclastic beds to nodular limestones constitutes the Highstand System Tract (HST). Rather than spectacular erosional surfaces, each of the six sequence boundaries in the Thebes Limestone at Gebel Gurnah corresponds to a contact between nodular limestone formed through early diagenesis at shallow depths in the absence of sedimentation, and overlying marls that were deposited in 100 to 200 m water depth and are the deepest lithofacies recorded in the formation.

Sequence Thebes 2 (96.30 m thick) is the thickest and best developed. Encompassing Units B to E, it begins with marls and marly limestone (Subunits B2, B3) overlying the Lowstand System Tract (LST) lag deposit of Subunit B1, continues with fine-grained limestone (e.g., Subunit B6) which grades up into indurated limestone (Subunit C4b to D4), itself capped by nodular limestone NLE of the HST. Sequence 1 (93.5 m-thick) which spans lithologic Unit A is almost equally well developed, ending with the terminal nodular limestone NLA, although without basal marls. Sequence Thebes 4 (77.4 m-thick) and Sequence Thebes 5 (36 m-thick), which include lithological Units H to J and K and L, respectively, are also bounded by nodular limestones (NLJ and NLL). The extremely thin (12.8 m) Sequence Thebes 3 is reduced to a basal marl (LST) and terminal nodular limestones (LNG; HST). Lithological Unit M with *Turkostrea* coquinas (the shallowest lithofacies in the whole succession) is interpreted as representing the HST at the base of a sixth sequence which we name here Sequence Minia 1 (see below).

Vertical trends in the proportion of planktonic foraminifera in Sequences Thebes 1 and 2 (although only approximate due to the indurated lithologies), indicate grossly decreasing-upwards trends in each (Fig. 15). This is consistent with the interpretation of the individual lithofacies and macrofaunas, which indicate shallowing-upwards trends in the individual sequences. Planktonic foraminifera are rare in Sequence Thebes 3, but a similar environmental trend is evident. A fifth shallowing-upwards sequence (Sequence Thebes 5) is characterized by the presence of thin, single or multiple *Turkostrea* shell beds in the lower part. The bases of Sequences Thebes 4 and 5 are interpreted as combined sequence boundaries and transgressive surfaces, and each sequence is interpreted as comprising a TST and a HST although their boundaries are not distinctly apparent. Sequence Thebes 5 is abruptly overlain by a massive *Turkostrea* coquina (Unit M). This is interpreted as a decrease in water depth associated with a reduction in sedimentation rates. The top of this unit is interpreted as a sequence boundary (base of Sequence Minia 1).

The overall distribution of planktonic and benthic fossil groups indicates that an overall shallowing-upwards trend is superimposed on the six individual shallowing-upwards sequences (Fig. 15). Radiolaria are present only in Unit A, which also has the highest proportions of planktonic foraminifera. The latter decreases to near zero at the top of Unit C, just above the lowest occurrence of calcitic molluscs and larger foraminifera. A restricted benthic foraminiferal assemblage begins at the base of Unit H. Molluscs become common from the base of Unit K, and *Turkostrea* shell beds begin in the lower part of Unit K. A similar overall shallowing-upwards trend can be identified at other localities in the Nile Valley and elsewhere in Egypt, and was already identified by Snavely et al. (1979). They also concluded that their 'upper member' at Gebel Duwi indicated an abrupt shallowing, which they interpreted as a sequence boundary. It is probable that this corresponds to the base of Sequence Minia 1 (see below).

VI- Mineralogy

The whole rock and clay mineralogy provides important information as to the environmental conditions that existed in southern Egypt during deposition of the Thebes Formation. In addition, the percentage of sepiolite to palygorskite, which represents the strength of continental influence on epicontinental deposition, supports our interpretation of the Thebes Limestone as an upwards shallowing sequence and allows us to tentatively delineate/identify the system tracks in each sequence (Fig. 14).

VI-A- Whole rock mineralogy (Fig. 14)

The whole rock samples are composed of calcite, ankerite, fibrous (sepiolite and palygorskite) and other clays, quartz and carbonate apatite (Fig. 14). Calcite is the dominant mineral, reaching at some levels 100% of the rock. Its abundance mostly varies between 30 and 70%, falling only occasionally to only a few percent (as in the red marls of Subunit B5). Ankerite (which is a magnesium-calcium-iron carbonate) is present in small amounts at nearly all stratigraphic levels analyzed here, but it also reaches amounts greater than 20-25 %. It is absent in limestone in which calcite is the only carbonate present without any dolomite (in Units A [Th50.35)], C [Th160], D [Th171.8], in E [Th192.5], E [Th254 and 262], J [Th281] and L [Th296.9]).

Fibrous clays vary between only a few percent and 70-90%. Together with other clays (see below), they constitute 40-50 % of the shelly/clayey beds (Subunits C1 [reddish grey marl] and F4 [purple marl]). They are very abundant (70-90%) in Subunits B2 (argillaceous limestone), B5 (red marl) and H3 (soft limestone). The whole clay fraction is sometimes very low (0 to a few %) in abundance. Non-fibrous clays are regularly present but in small amounts (1-15%), although occasionally they reach 70% of the whole clay fraction (fibrous and non-fibrous clay minerals), as for instance in Subunit H3. Quartz is also regularly present as traces (~1%). Nevertheless, it is notably more abundant (~5%-~25%) in Unit B (Subunits B1 [phosphate-rich limestone], B3b [grey marl] and B5) and in our only sample of flint (TH 122.5, 12%). Carbonate apatite (francolite) is rare in the succession, occurring in close association with quartz at the base of the Subunits B1 (9%), B2 (2%) and B5 (a few percent).

The co-occurrence of ankerite and fibrous clays gives the formation a strong magnesian character that may be interpreted as evidence of an aridity trend in the region (Hillier, 1995) during the Early Eocene. The presence of ankerite rather than dolomite is probably indicative of the immediate availability of iron together with magnesium on the Egyptian stable platform, both reflecting more or less continuous continental influence. A diluted but sustained terrigenous input is also indicated by the persistence of quartz (traces) throughout the succession. In addition, the association of significant increases (2.3–10%) in quartz content with sporadic, at least partly detrital clay layers (e.g., the argillaceous limestone and marl of Subunits B2, B3, B5, F2 and H2) supports propinquity of the nearby continent. The highest content (25%) in quartz is recorded in the thin indurated limestone of Subunit B1 (which contains grains and coatings of francolite), providing further evidence of a strong influx of nutrients from the continent.

VI-B- Clay mineralogy

The clay fraction in the Thebes Formation is largely dominated by the fibrous magnesian clays, sepiolite and palygorskite, although with broad variations in abundance (Fig. 14). They may constitute either the entire clay fraction (100% in Subunits A4 and Units G, H, I and K) or a very small part of it (<10% in Unit K). The relative proportion between the two minerals is also highly variable. Sepiolite dominates in most of the succession, often reaching 80-90% of the clay assemblage. However, palygorskite becomes very abundant over restricted stratigraphic intervals, reaching peaks of ~90% at the contact of Units C and D, in mid-Unit I and in lower Unit K. Its abundance also reaches ~ 20-35 % in Unit A, at the contact between Units B and C, and in Units F and G, and >60 % at the base of Unit B.

The remainder of the clay fraction consists of, in decreasing proportions, illite-smectite (ISR0 type randomly mixed-layer), illite, chlorite and kaolinite (Fig. 14). The variations in abundance of ISR0 (randomly illite-smectite mixed layers - mxl) are considerable, from ~ 2% to ~ 90%. Illite ranges between a few percent and ~ 15%. Chlorite and kaolinite remain at a very low level of a few percent.

The association of illite, kaolinite and chlorite together with ISRO mxl in specific stratigraphic intervals is likely indicative of temporary influx of detrital material spreading over the dominantly calcareous (and siliceous) shelf. Two regimes may be inferred. The seven distinctive marls in the succession (see above) may have been deposited rapidly through major, direct detrital influx in the absence or near absence of carbonate (and silica) input. In contrast, the presence of the above clay association in bioclastic/oyster-rich limestone intervals may result from environmental shallowing.

The clay mineralogy thus confirms the implication from bulk mineralogy that arid regional conditions prevailed during the Early Eocene in southern Egypt. It also shows stabilization of a magnesian-influenced sedimentation.

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VI-c- The SP*

As explained above, the abundance of sepiolite and palygorskite in marine limestones varies as a function of the Mg/Al ratio that increases basinwards (Isphording, 1973). The ratio of these two authigenic fibrous clays, together with detrital clay data, may thus be tentatively used as a proxy of distance of a marine location from the seashore.

We have shown above that the Thebes Formation at Gebel Gurnah is an upward-shallowing succession, which was deposited at outer neritic depths at the base and in inner neritic environments at the top. The obvious increase in dominance of palygorskite over sepiolite in the section (together with a SP* changing from a high of 90% at ~ 50 m to a low of 60% at ~ 320 m} reflects well this shallowing, and confirms our determination from lithofacies and paleontologic indicators. However, superimposed on this general trend, there are episodic, abrupt and massive fluctuations of the abundance of palygorskite and extended intervals of abundant sepiolite, and their distribution pattern appears to be repetitive in the five sequences.

Three prominent peaks (P1, P2, P3) represent major increases (80 to 95%) of palygorskite in the clay assemblages. They alternate with extended sepiolite maxima (and correlative palygorskite minima) with high values of 90-95% sepiolite reached at some levels. In sequences Thebes 2 and 4, other minerals such as chlorite, illite, ISR0 mixed-layers and kaolinite occur over restricted intervals corresponding to claystone beds A, B, C, F and H. Several of these occurrences coincide with small to moderate, albeit abrupt, peaks of palygorskite (~15-20% in B, ~40% in A, C, F and H). Based on these clay distributions, it is possible to divide Sequences Thebes 2 and 4 into three intervals. The lower interval is dominated by sepiolite but with peaks in detrital clay minerals of continental origin associated with palygorskite (maximum S2 extending from Unit B to mid Unit C for Thebes 2; maximum S4 extending from Unit H to mid Unit I for Thebes 4). The middle interval is strongly dominated by palygorskite and eventually associated with continental inputs of detrital minerals (Peak P1 limited to the top of Unit C and base of Unit D in Thebes 2 ; peak P2 at the top of Unit I for Thebes 4). The upper interval is again dominated by sepiolite, with, here and there, continental influxes of detrital clays (Maximum S2 occurring in Units D and E for Thebes 2 ; Maximum S5 extending from the top of Unit I through Unit J for Thebes 4). With regard to the relation between the Mg/Al ratio and the distance of the locus of deposition-seashore, the tripartite division of the two sequences would imply the succession of distal deposition (lower interval), proximal (middle interval) and distal again (upper interval). In terms of sequence stratigraphy, this would indicate the succession of a retrograding transgressive system leading to the migration of the locus of deposition from offshore towards the continent (lower interval in both Sequences Thebes 2 and 4), and resulting in maximum flooding with momentary sedimentation close to the continent (middle interval in both Sequences Thebes 2 and 4). The highstand wedge that follows progrades so that the distance of the locus of sedimentation to the continent increases (upper interval in both sequences).

If this is correct, the most complete sequences in the Thebes Formation at Gebel Gurnah are Sequences Thebes 2 and Thebes 4. The main difference is that Thebes 2 includes the phosphate-rich lag deposit of (probably) the LST at its base. Sequence Thebes 5 is quite incomplete, the TST being missing. It begins with the maximum flooding surface (marked by peak P4). The HST is well characterized by the dominance of detrital (kaolinite) and derived (illite chlorite and ISRO) clays that dominate the sepiolite clays. Sequence Thebes 3 is clearly incomplete.

The least characteristic sequence is Sequence Thebes 1, with dominant sepiolite indicating greater distance from the shore. This is in agreement with our interpretation of deposition at outer neritic depths. Our sampling resolution is too low to allow any further description of this sequence.

VII- Biostratigraphy of the Thebes Formation

A review of biostratigraphic investigations of planktonic foraminifera of the section at Gebel Gurnah (including a recently discovered study by Hamam, 1971) is presented in Appendix 3. We focus here on an investigation made by one of us (WAB) in connection with this study which was begun before discovery of the investigation by Hamam (1971).

VII-A- Planktonic foraminifera

Fifty one samples, spanning the highest 6.3 m of the Esna Formation and the interval from 0.0 m to 248.0 m in the Thebes Formation, have been examined from Gebel Gurnah. These were selected from the full series of microfaunal samples analyzed as containing the best-preserved material (although still mostly poor).

Planktonic foraminifera occur in most samples in the Thebes Formation up to 248 m, but preservational bias (most individuals are coated with chalky encrustation obscuring surface details) has inhibited identification (Table 5). The best-preserved specimens are from the more marly intervals. Cleaning the surface has improved preservation in some instances, but secondary recrystallization remains an obstacle to observing wall texture. The richest assemblages/occurrences of planktonic foraminifera were found in samples from 94.1 m, 111.05 m and 134.5 m. Few planktonic foraminifera occur in samples taken above 232 m and virtually none above 244 m. The taxonomy and stratigraphic ranges of planktonic foraminiferal taxa discussed below are based on data in Pearson et. al., eds (2006).

Planktonic foraminiferal assemblages in the uppermost Esna Shales are characterized by a diverse assemblage of *Acarinina*, *Morozovella*, *Igorina*, *Pseudohastigerina* and *Subbotina* (see Table 5). Diversity is strongly reduced in the Thebes Formation reflecting the pronounced shallowing in the upper (carbonate) part of the section. The most common and characteristic taxa in this formation include: *Pseudohastigerina wilcoxensis*, *Acarinina interposita, A. pentacamerata*, *A. pseudotopilensis* and *A. wilcoxensis.* Less common, but stratigraphically characteristic forms include *A.* cf*. alticonica*, *A. angulosa, A.* cf *boudreauxi*, *A. coalingensis*, *A. esnaensis*, *A. primitiva*, *A. quetra*, *A. soldadoensis*, *A. wilcoxensis*, *Morozovella aragonensis*, *M.* cf. *lensiformis*, *Parasubbotina inaequispira*, *Planorotalites pseudoscitula* and *Subbotina patagonica/roesnaesensis complex*.

Relative age determination

Esna Shale Formation: The upper Esna Shale Formation contains a typical Zone E4/P7 (lower Ypresian) faunal association, dominated by acarininids and including *Acarinina angulosa, A. esnaensis, A. interposita, A. wilcoxensis, A. primitiva, A. pseudotopilensis, A. soldadoensis, Morozovella aequa, Morozovella* sp. cf. *M. crater, M. gracilis, M. subbotinae, Igorina broedermanni* and *Pseudohastigerina wilcoxensis.* We have not observed *Morozovella formosa* s.s. in our material at Gebel Gurnah, but it was recorded (and correctly identified and illustrated) by Hamam (1971) over approximately the upper 20 m of the Thebes Calcareous Shale (= Qurnah Calcareous Shale of this paper) and has its HO at the same level as the LO of *M. aragonensis* (sample 20) at the Thebes calcareous Shale/Thebes Formation boundary. This demonstrates that Zone P7/E5 extends at least as low as the base of the Thebes Formation and, indeed, we have observed *M. aragonensis* as low as 3 m below the base of this formation.
Thebes Formation: The faunal elements/assemblages listed above are characteristic of the Lower Eocene (Ypresian), although *Morozovella aragonensis* (Zone E5-9 [Zone P7-11] recorded by Hamam (1971) from ~20-48 m and by us up to at least 244 m) ranges into the Middle Eocene (Fig. 16). While the HOs of several acarininids (i.e., *alticonica* [Zone E4-7 [Subzone P6b-9]), *coalingensis* [P4c-E7/P9], *pentacamerata* [E5-7= P7-9], *pseudotopilensis* [Zone E1-7 = Zone P5 (upper part)-P9], *soldadoensi*s [Subzone P4c-P9/E7) lie in Zone E7

[Zone P9], the presence of *Ac. esnaensis* (Zone P4c-E5/Zone P7), *wilcoxensis* (HO in Zone P5-E5/P7), and/or *Morozovella aragonensis* (LO in Zone E5= Zone P7) as high as 232-235 m and 244 m suggests that the Thebes Formation (up to 244 m) also belongs to Zone E5/Zone P7 (mid-Ypresian), and indeed somewhat higher/younger biostratigraphic level(s) (see Fig. 16 and Appendix 4).

This age determination can be compared to that by Krasheninnikov and Ponikarov (1965) in the Luxor area, by Krasheninnikov and Abdel Razik (1969) in the Quseir region, by Said (1990) in southern Egypt, and by Berggren and Ouda (2003a) at Dababiya. The latter authors placed the base of the Thebes Formation at what would currently be considered Zone E6/P8 and considered the Thebes Formation to range as high as Zone E7/P9. We have found no evidence of a younger age (E6-7/P8-9) in the form of *Acarinina bullbrooki, Ac. cuneicamerata, Subbotina frontosa* (cf. Berggren and Ouda, 2003a, p. 75, 78), *i. al*., and now consider these data suspect, although it is quite conceivable, and indeed likely, that the upper part of the Thebes Formation could be stratigraphically equivalent to Zone E6/P8 and also younger levels (see Fig. 16 and Appendix 4). Nor have we found *Acarinina aspensis, Ac. collactea, Ac. mcgowrani, Ac. praetopilensis,* or the stellate *Astrorotalia palmerae* or *Planorotalites capdevilensis*—all indicative of a maximum zonal assignment of Zone E7/P9, in any samples of the Thebes Limestone, and this can most probably be ascribed to unfavorable facies development (see Appendix 4)

VII-B- Calcareous nannofossils

Calcareous nannofossils, and specifically the stratigraphic markers, were scarce at most levels in lithologic units younger than Unit B2. This is due to diagenetic processes affecting formerly nannofossil-rich sediments. There is a clear correlation between coccolith abundance and diversity on the one hand and on the other hand 1) high diversity and good preservation (Table 6), 2) low diversity and overgrowth of nannofossils, and 3) the character of the matrix (micrite to sparite). Additionally, isolated occurrences, in samples with poorly preserved assemblages, of species that are rarely abundant even when preservation is good (e.g. *Lophodolithus nascens*) indicate a considerable loss of paleontologic information.

Only a few levels still retain abundant calcareous nannofossil assemblages. At most of these levels *Tribrachiatus orthostylus* is overwhelmingly abundant compared with asteroliths, particularly the marker *Heliodiscoaster lodoensis*, with which it occasionally occurs (in Zone

NP12). At level 94.5 m the ratio between the two species is 2:234 (2 asteroliths of *H. lodoensis* vs 234 coccoliths of *T. orthostylus*). The absence of *H. lodoensis* in samples with poorly preserved assemblages yielding *T. orthostylus* has therefore no biostratigraphic significance or implication. The abundance of *T. orthostylus* in the Thebes Formation is also a function of preservation, which was a problem for establishing its HO. Thus counts of these two taxa, as well as a few others, have been made for key stratigraphic intervals, providing a general idea of their frequencies at these levels.

Relative age determination

The age determination relies on assemblages from four stratigraphic levels (0 m, 4.65 m, 94.5 m and 232.0 m), which have yielded common, generally well preserved, diversified calcareous nannofossil assemblages (Table 6; Plate 1). The lower three levels are unambiguously assignable to Zone NP12, with *Tribrachiatus orthostylus* common and *Heliodiscoaster lodoensis* very rare. Additionally level 94.5 m has yielded *Chiphragmalithus calathus* (which is restricted to Zone NP12). Level 232.0 m has yielded *Heliodiscoaster lodoensis* together with *H. cruciformis*, a species common in the shallow Wittering Formation of the Bracklesham Beds of the Hampshire Basin (Aubry, 1986). The latter species ranges from upper Zone NP12 to lower Zone NP13. Level 232 m thus belongs to either upper Zone NP12 or lower Zone NP13. The absence of *T. orthostylus* at this specific level would indicate an NP13 zonal age. However, the HO of *T. orthostylus* in the section is difficult to determine. Its abundance decreases sharply between levels 142 m and 148 m. It is absent in the interval between 178.8 m and 184 m. Characteristic specimens occur at 240.5 m and 244 m. Several poorly preserved specimens recorded at levels 235 m, 248 m, 288.7 m, and 304 m are tentatively referred to *T. orthostylus*. A single characteristic specimen was encountered at level 289.8 m. This unexpected record may be interpreted as reflecting preservational bias. More compelling, however, is the distribution of *T. orthostylus* with regard to the lithologic succession (Fig. 17). This shows that the absence of *T. orthostylus* (in the mid part of the section) and its rare occurrences (in its upper part) are typical of the concretionary and nodular limestones of the HSTs, suggesting, in turn redeposition of fine particles transported by weak currents. It is worth noting that our sample at 232 m (with *H. lodoensis* and *H. cruciformis*, but no *T. orthostylus*) is from a fine-grained limestone of the TST of Sequence Thebes 4, whereas the few lone occurrences of *T. orthostylus* above this level are from the concretionary limestones of the HST of the same sequence. Reworking in these shallow water deposits with very low sedimentation rates would be readily apparent, which allows us to conclude that *T. orthostylus* is reworked in the upper part of the Gurnah section and to assign confidently Level 232 m to Lower Eocene Zone NP13.

Discussion

Previous studies (Perch-Nielsen et al., 1978; El Dawoody, 1984, 1993; Faris and Strougo, 1998) have reported on the general low occurrence and poor preservation of coccoliths in the Thebes Formation and this study is no exception, even though Tawfik et al. (2010) reported good preservation. Despite this, and with the exception of Boukhary and Abdelmalik (1983; see Caption Fig. 17), very similar inventories have been established in these different analyses, including ours (Fig. 17). Because samples were taken at different stratigraphic intervals in these studies, we infer that the composition of the nannofossil assemblages was quite homogenous throughout the section. On the other hand, the biozonal dating of the formation has been a vexing problem due to the scarcity of *Heliodiscoaster lodoensis*. Because of this, Hassan et al. (1978) preferred to assign the bulk of the Thebes Formation at Gurnah, to a "*Discoaster binodosus–Marthasterites tribrachiatus* Interval Zone" defined by them as the interval between the HO of *Heliodiscoaster binodosus* and the HO of *Tribrachiatus orthostylus*. (These authors assigned the lower 9.5 m of the Thebes Formation to their "*Marthasterites bramlettei-Discoaster binodosus* Interval–zone" between the HO of *T. bramlettei* and the HO of *H. binodosus*). We have positioned the samples analyzed by previous authors (except Hassan et al., 1978) in our own log, using both their measurements of the section and lithologic description. Even if approximate, this shows a good complementarity of the four studies and emphasizes similar results. Faris and Strougo (1998) and Tawfik et al. (2010) sampled the Thebes Formation up to lithologic Units C and D, respectively. With only a few samples analyzed, the latter authors did not recover *H. lodoensis* and assigned the section to Zone NP11. With greater sample resolution, Faris and Strougo (1998) recovered *H. lodoensis* from Unit B, as have we. Like these authors we are confident that the Thebes Formation belongs, at least up to 178 m, to Zone NP12. The question, however, is the extension of this zone in the section. Neither Perch-Nielsen et al. (1978), nor Faris (1991) or Faris and Strougo (1998) recovered *H. lodoensis* from the lowest few meters of the Thebes Formation. However, El Dawoody (1983, 1994) reports on the occurrence of the species in the lower ~20 m of the section, which this study confirms (Fig. 17 and Table 6). It is rare, and with less than pristine preservation, but this six-rayed form is sufficiently characteristic as to be identifiable in moderately well preserved assemblages. The base of the Thebes Formation thus lies in Zone NP12.

More difficult is the zonal assignment of the upper part of the formation, although we confidently assign level 232 m to lower Zone NP13. The discontinuous occurrence of *T. orthostylus* and its sharp decrease in abundance above 178 m in the section may be interpreted as reflecting either reworking or upward shallowing resulting in restricted planktonic communities. Indeed, the water depth had decreased enough for planktonic foraminifera to be essentially absent between stratigraphic levels 170 to 200 m, and to occur only sporadically and rarely above level 200 m (Fig. 17). Our preferred interpretation, however, is that in-situ coccolithophores above 178 m occur mostly in the fine-grained limestones deposited during TSTs, whereas only robust, diagenetically-resistant coccoliths (such as *T. orthostylus*) occur in the shallow bioturbated concretionary and nodular limestones of the HSTs (see above). Our sampling conducted synchronously with logging did not sufficiently represent the TST deposits and other fine-grained limestone. High resolution sampling of the latter (which has not been possible owing to the current political situation in Egypt) may lead to precise biozonal assignment of sequences D to F. However, even if the biostratigraphic age was precisely established for TST limestones above 178 m, the dominance of HSTs deposits above this may lead to difficulty in precisely delineating the NP12/NP13 zonal boundary in the section.

In summary, based on our data, we confidently assign lithologic Units A to C of the Thebes Formation at Gebel Gurnah to Zone NP12 and Unit H (at 232 m) to lower Zone NP13. We are unable at this time to determine the upward extent of Zone NP12 and the downward extent of Zone NP13, and we recognize that precise delineation of the NP12/NP13 zonal boundary in the section is uncertain because of the predominance of HSTs deposits above 187 m.
Although some omission surfaces are prominent in the upper part of the Thebes Formation, there is no erosional contact that would suggest a potentially important stratigraphic gap such that upper Zone NP12 is missing in the section (although we note the thinness of Units F and G in Sequence Thebes 3). We thus infer essentially continuous deposition throughout the section during Biochron NP12 to early Biochron NP13. This is supported by correlation to global sequence stratigraphy (see below).

VII-C- Pteropods

The phosphate-rich limestone Unit B1 contains common phosphatised pteropods, kindly identified by A. Janssen. Only small samples have been available, but the sample at 93.5 m yielded *Altaspiratella bearnensis* (Curry, 1982) (2 specimens), *Limacina pygmaea* (Lamarck, 1805) (2 specimens) and *Limacina* sp. nov. ? (3 specimens). The sample at 94.1m yielded

Limacina sp. nov. ? (6 specimens). The probable new *Limacina* is too poorly preserved and too juvenile to introduce a new species. This is apparently the first record of Early Eocene pteropods from Egypt (and may be from North Africa). *Altaspiratella bearnensis* has previously been recorded from the Aquitaine Basin (upper Zone NP12/lower Zone NP13) and the London Basin (Zone NP12) (Cahuzac and Janssen, 2010) and Uzbekistan (upper Zone NP12) (King et al., 2013). *Limacina pygmaea* ranges from upper Zone NP12/lower Zone NP13 to NP14, and is recorded from NW Europe, the Aquitaine Basin and Uzbekistan (Cahuzac and Janssen, 2010; Janssen et al. 2011). Together these records indicate probable correspondence with upper Zone NP12, which is consistent with the nannofossil and planktonic foraminiferal dating.

VIII- Tentative correlation of the Thebes Formation to the framework of global sequence stratigraphy: Implications.

The biostratigraphic data delineated in this study concur in support of direct assignment of the Thebes Formation at Gebel Gurnah to planktonic foraminiferal Zone E5/P7, and its mid-part (indirectly) to Zone E6, and to calcareous nannofossil Zone NP12 to Zone NP13 of the Lower Eocene (Ypresian). The overlap of Zones E5 and NP12 implies that the base of the Thebes Formation lies well within Zone NP12, not close to the base of this zone as the LO of *H. lodoensis* a few meters below the Esna Shale/Thebes formational contact would suggest. Nevertheless, the duration encompassed by the Thebes Formation at Gebel Gurnah is difficult to determine. The LO of *M. aragonensis* (which defines the base of Zone E5) is located 3 m below the base of lithologic Unit 1, based on coarse sampling of the upper 6 m of the Qurnah Calcareous Shale Member (see Appendix 4). The base of the Thebes Formation is thus younger than the FAD (First Appearance Datum) of *Morozovella aragonensis* at 52.5 Ma (Gradstein et al., 2012). There is even greater difficulty in dating the top of the formation. It is clearly younger than the LAD (Last Appearance Datum) of *T. orthostylus* (marker of the NP12/NP13 biochronal boundary) with an age of 50.66 Ma (Agnini et al., 2014). No estimated ages of the FAD and LAD of *H. cruciformis* are yet available. In the absence of biostratigraphic data, we turn to our framework of depositional sequences to identify the SB between Sequences Thebes 5 and 6 (see above). The main tenet of sequence stratigraphy is that the sedimentary record consists of a succession of eustatically controlled, globally correlative depositional sequences (Vail et al., 1977; Neal and Hardenbol, 1998).

Earlier lithologic logs of the Thebes Formation at Gebel Gurnah are difficult to integrate with the one we present here, in part because the measurements of the thickness of the section are inconsistent in different works, (e.g., 290 m in Said [1960] versus ~340 m herein), and in part because different criteria were used for subdivision. Nevertheless, sound correlations are possible. For instance, based on the range of *Nummulites* and *Operculina* it is possible to approximately correlate Said's Beds 2 and 3 with our Units E to K. The most informative log of the Thebes Formation in the central Nile Valley to date is that of Snavely et al. (1979) who divided the formation into three members, lower, middle and upper, and showed the middle member to include four intervals of nodular limestone which are easily equated (by counting downwards) with NLL to NLE (Fig. 18). They also correlated the Thebes succession in the Nile Valley with that on the Red Sea Coast, particularly at Gebel Duwi, where they also documented four intervals of nodular limestone, albeit with decreasing thickness downwards (Fig. 18). In both areas Snavely et al. (1979) delineated a thin upper Thebes Member. In the central Nile Valley, this member is comprised of "interbeds up to several meters thick of oyster limestone and oyster shell debris" (op. cit., p. 351). This clearly corresponds to Said's "Bed n° 1 – Yellow silicified limestone with *Gryphea pharaonus*, *Ostrea multicostata* and *Nummulites subramondii*" (Said, 1960, p. 279) and to our Unit M (see Fig. 8f). In the Eastern Desert, the upper member consists of "fine-grained limestone, locally interbedded with oyster and shell hash (commonly cross bedded), minor fine-grained clastic limestone-chert sands and calcrete (caliche) and silcrete surfaces" (op. cit., p. 355) and it immediately overlies a nodular bed (NLL) as at Gebel Gurnah. It is thus also correlative with our Unit M. Finally, Snavely et al. (op. cit., p. 352) indicate that in the northern-central Nile valley, the upper member is represented by "up to several meters of festoon cross-bedded alveolinid lime sand […] resulting from mechanical concentration of the benthic foraminifera". This shows that our Unit M is of broad areal extent, passing laterally from shallow oyster-rich deposits (Central Nile Valley) to very shallow carbonate deposits with evidence of episodic subaerial exposures (Eastern Desert) to calcareous sands forming "cross-bedded dune structures" (northern-central Nile valley). These lithologies are indicative of an episode of extensive inner neritic deposition with evidence of strong current activity in contrast to the preceding period of tranquil deposition on the carbonate platform (see above), an episode which Snavely et al. (op. cit., p. 356) inferred to represent a "rather rapid drop in sea level […] near the end of Ypresian time". Lithologic evidence of a rapid late Early Eocene sea level fall is also seen in the upper 50 m of the Thebes Formation in the Sinai where a 20 m thick, phosphatic-rich deposit (interpreted as lag deposit) contains reworked planktonic foraminifera (Abul-Nasr and Thunell, 1987). These authors indicate that similar correlatable lithologies occur as well in Israel, Jordan and Syria.

We have demonstrated above that the Thebes Formation (sensu Said 1960) consists of six depositional sequences, with Unit M corresponding to the LST at the base of Sequence Thebes 6. Although we cannot date precisely each sequence, let alone each SB, our finding that stratigraphic level 232 m in Subunit H3 of Sequence Thebes 4 belongs to lower Zone NP13 allows us to position the younger sequences in the global framework of sequence stratigraphy (Neal and Hardenbol, 1998; Fig. 19). Positioning the boundary between Sequences Thebes 3 and 4 as corresponding to SB Yp8 initially results in a remarkable match between regional sequence stratigraphy in Egypt and global sequence stratigraphy (Gradstein et al., 2012). Most importantly it results, from straightforward superposition, that the boundary between Sequences Thebes 5 and 6 corresponds to the major late Early Eocene drop in sea level marked by SB Yp10 at 49.6 Ma, which in turn implies that level 326 m at Gebel Gurnah is ~ 49.6 Ma. There is no evidence of erosion at the top of Sequence Thebes 5, only indication of extremely slow sedimentation rates, and there is no need at this time to infer a significant stratigraphic gap. Proceeding in numeric order downwards the boundaries between Sequences Thebes 4/Thebes 5, Thebes 3/Thebes 4, Thebes 2/Thebes 3 and Thebes 1/Thebes 2 are then identified as, respectively, SB Yp9, Yp8, Yp7 and Yp6 of global sequence stratigraphy (Neal and Harbenbol, 1998), currently dated at 50 Ma, 51 Ma, 51.5 Ma, 52.4 Ma (Gradstein et al., 2012).

For all its apparent conformity with global sequence stratigraphy, the sequence record of the Thebes Formation constitutes a test of the accuracy of the age of some of the global SBs as shown in Gradstein et al. (2012). It also constitutes a test of the global synchrony of depositional sequences in tectonic stable areas. Such discussion is beyond the scope of this paper, and it will be raised elsewhere. However, we briefly address here two concerns, which we consider significant enough for us to regard correlation of the Thebes sequences with global sequences as preliminary and indeed tentative. One concern is about the age of the MFS between Yp8 and Yp 9 SB, and whether Sequence Thebes 3 and 4 precisely correlate with the two “global” sequences between SB Yp8 and SB Yp10. The other concern is about the age of Yp6 and whether Sequences Thebes 1, 2 and 3 are not offset with regard to the “global” sequences between SBs YP6 and Yp8. Regrettably, the lack of biostratigraphic and magnetostratigraphic data hampers direct assessment of the ages of Sequences Thèbes 2 and

3. However, we remain confident in the identification of SB Yp10 at 326 m because this is a well-documented event in numerous stratigraphies (e.g., Aubry, 1991; Dupuis et al., ed., 1991).

Sequence Thebes 4, which is 77 m-thick, is almost fully developed (see above), with an extended TST (Unit H through Subunit Ib; 212.6 m to 254 m), a MFS spanning essentially Subunit Ic (254-258 m), and a HST comprised of most of Subunit I2 and Unit J. In Sequence Thebes 4, the MFS is thus located ~22 m above level 232 m in the TST and it lies in the lower part of Zone NP13, implying that the global MFS (assuming eustasy) should be markedly younger than the NP12/NP13 biochronal boundary to which it is currently calibrated (see Fig. 19). This, in turn, implies that the Yp9 SB is somewhat younger than 50 Ma.

SB Yp6 is dated at 52.4 Ma in Gradstein et al. (2012), which is slightly younger than the FAD (First Appearance Datum) of *Morozovella aragonensis* at 52.5 Ma. The LO of this taxon at Gebel Gurnah is located at least 3 m below the base of the Thebes Limestone Formation, in the Qurnah Calcareous Shale Member of the Esna Shale Formation. Thus, the base of the formation and Sequence Thebes 1 lies in Zone E5, and is therefore younger than 52.5 Ma, but it is also older than 52.4 Ma. If the SB between Sequences Thebes 1 and 2 corresponds to SB Yp6, as we have inferred above, the 94.8 m of fine-grained limestone that compose Sequence Thebes 1 were deposited in less than 100 kyr. This, in turn, implies that this pelagic deposit was deposited at a rate in excess of 90 cm/10^3 yr, which is unlikely. Reliance on global sequence stratigraphy forces us to assign an age of ~52.45 Ma to the base of Sequence Thebes 1, while other considerations (MPA, WAB, unpublished) indicate that it must be substantially younger.

A possibility is that the calibration of the late Ypresian framework of global sequences is inaccurate and requires revision. In this perspective, the dating of SB Yp6, in particular, is considerably off. For this reason, we propose two ages for the base of the Thebes Formation: a forced, albeit probably too old age of 52.45 for the base of Sequence Thebes 1 and an arbitrary age of 52 Ma. Another possibility is that the thin sequence Thebes 3 is regional, with only sequences Thebes 1, 2, 4 and 5 being global sequences. A third possibility is that the preliminary matching between the Thebes sequences and the Ypresian global sequence is coincidental. This is a particular sensitive point for sequences that have formed during the EECO (Early Eocene Climatic Optimum), when glacioeustasy is unlikely to have been an active forcing on sedimentary patterns. We are unable to resolve the two conflicts delineated above at this time, and opt to continue the discussion based on the precept that the five sequences Thebes 1 to 5 approximate well the global sequences. This allows us in turn to compare our record of long-term shallowing with detailed Early Eocene sea level history reconstructed based on evidence from epicontinental New Jersey.

We have demonstrated that the Thebes Formation is a regressive sequence that has recorded variations in sea level during the late Early Eocene in the form of 6 successive Ypresian sequences. Estimates of global sea level change during this time by Miller et al. (2015; Fig. 19) shows a progressive decrease of ~40 m between SB Yp6 (52.4 Ma) through SB Yp8 (51 Ma). This global decrease at a rate of ~ 29 m/Myr over a 1.4 Myr duration clearly parallels the decrease in regional sea level that has resulted in the shallowing upwards from Sequence Thebes 2 through Sequence Thebes 3 (Fig. 19), a 118 m thick sedimentary interval that was deposited at a rate of 85 m/Myr over the same duration (without correction for compaction). The Thebes Limestone Formation is a neritic deposit (<200 m paleodepth; see above).

The combined effect of sea level lowering at a rate of 29 m/Myr and sedimentary accumulation at rates of 85 m/Myr over a 1.4 Myr interval between 52.4 and 51 Ma would have resulted in a shallowing of ~158 m in 1.4 Myr, and, in the short term, the subsequent rapid filling of the basin in the Thebes area (this is a minimum value for shallowing considering that the accumulation rates are not corrected for compaction). This would have happened much before 49.6 Ma when *Turkostrea* coquinas indicate that as a matter of fact very shallow water (inner neritic, 0–30 m) conditions were established. To prevent shallowing to neritic depth shortly after 51Ma, active subsidence must have compensated for shallowing, allowing thus formation of another 148 m of sediments over the next 1.4 Myr (51 Ma to 49.6 Ma). We estimate that subsidence rates in the order of 75 m/Myr would have been necessary to maintain the accommodation sufficient for continued deposition over the ~2.8 Myr that it took for deposition of the Thebes Formation. Depending on sea-level history between 51 and 49.6 Ma, it is possible, however, that subsidence decreased progressively as sequences Thebes 4 and 5 were forming. High subsidence rates are unsurprising in the context of the Paleocene-earliest Eocene sedimentary history in Upper Egypt. By comparing the thicknesses and ages of Paleocene to Lower Eocene sections in Egypt, Aubry and Salem (2012) determined that the subsidence rates increased considerably during the Late Paleocene in this region, and proposed that this increase was related to the tectonic relaxation that followed the intense phase of tectonic activity along the

Syrian Arc Folds during the Middle and Late Paleocene (Chrons C26 and C25) in connection with the closure of the Neotethys Ocean.

IX- Emendation of the Thebes Formation

The stratotype of the Thebes Formation is now well documented, and regional sequence stratigraphy (delineation of sequences Thebes 1 to 5 and Minia 1) will constitute a powerful means for the correlation of distant sections of the formation across the Egyptian stable platform, even in the absence of biostratigraphy. A problem remains however, which concerns the upper limit of the formation. In contrast to the lower boundary of the formation which is well exposed and in the distinct/sharp contact with the Esna Shale Formation, no upper boundary was defined by Said (1960) and the contact with the overlying Minia Formation is not known in the stratotypic area. In fact, it is generally agreed that the contact between the two formations is not established (e.g., Boukhary and Abdel Malik, 1983; contra Snavely et al., 1979, see above). We have shown above that the uppermost part of the Thebes Formation, as defined by Said (1960), belongs to a different eustatic cycle than the bulk of the formation. The Minia Formation (Said, 1960) consists of shallow, alveoline-rich, white limestone, a lithology that is not known in Sequence Thebes 1 to Thebes 5 of the Thebes Formation. On the other hand, Snavely et al. (1979) report the presence of alveolines in Sequence Minia 1, in the eastern Desert as well as north in the Nile Valley towards Sohag. One solution to the dilemma of the Thebes /Minia formational contact is to define it so as to correspond to the SB between Sequences Thebes 5 and Minia 1. Sequence Thebes 5 would be the uppermost sequence of the redefined Thebes Formation whereas Sequence Minia 1 would be the lowermost sequence of the Minia Formation. Accordingly, we (M-P Aubry, C. Dupuis, W.A. Berggren) place the upper boundary of the *Thebes Limestone Formation* at the lithologic contact between Units L and M at meter 326 m in the Gebel Gurnah stratotype section, and emend the original definition of Said (1960, p. 279) to exclude the lithologies corresponding to our Unit M and now assigned to the (renamed) *Minia Limestone Formation*. To emphasize this emendation, we use the name "Thebes Limestone Formation" which was initially introduced by El Naggar (1966) and also used by Aubry et al. (2007) as a synonym of Thebes Formation to emphasize the lithologic contrast between this formation and the Esna Shale Formation. This name does not seem to have been used in the literature, and is thus appropriate for characterization of the emended Thebes Formation. The Thebes Limestone Formation is 236 m thick in the Gebel Gurnah type section, which is comprised of 12 lithologic units (Unit A to L) organized in five depositional sequences

(Thebes 1 to 5) assigned to Zones E5 and (indirectly) E6, and Zones NP12 and NP13. Its lower boundary is a sharp contact with the Qurnah Calcareous Member of the Esna Shale Formation; its upper boundary is the contact with Unit M of the Minia Limestone Formation which is a marked sequence boundary indicative of a sharp fall in relative sea level and most probably correlative with SB Yp10 of global sequence stratigraphy.

X- Implications for geoarcheological research

Acknowledgement of the importance of geological studies in providing a background to archeological research in Egypt is closely associated with the emergence of the concept of *Cultural Heritage* that largely developed during the second half of the 20th Century in recognition of the exceptional cultural wealth that the Pharaonic temples of Nubia (Upper Egypt) represent (Desroche-Noblecourt, 1992). As early as 1977, discussions of the geological background became an integral part of archeological activities on the West Bank, not only with regard to the evaluation of the risks and damages threatening the royal tombs but also, and more importantly, with regard to their preservation (Curtis, 1979, 1995; Curtis and Rutherford, 1981; Rutherford, 1990, Rutherford et al., 1977, 1995). More recently, integrated lithologic and structural frameworks as detailed and accurate as possible have become indispensable tools in Egyptian geoarcheological research (Aubry et al., 2009, 2015, 2016). Regional stratigraphic studies (Dupuis et al. 2003, Aubry et al., 2007) have provided the necessary background for stratigraphic correlations and geological mapping in the Theban Neocropolis (Dupuis et al., 2011). However, further studies are still necessary to precisely document the location of the Theban tombs in the local stratigraphy (Karlshausen and Dupuis, 2015). The Thebes Limestone Formation consitutes a substantial part of the substratum of the Thebes Mountain, and the lithologic log presented here constitutes a much needed geoarcheological resource. The lithologic variations described above in the Gebel Gurnah section occur throughout the West Bank and provide the possibility of fine-scale (bed to bed) correlation in the vicinity of the tombs and other antique monuments, whether in the Valley of the Kings or in the Theban hills at the foot of the Theban cliff. Most of the tombs of the Valley of the Queens, the Valley of the Kings, the Necropolis of Deir el Medineh and of Deir el Bahari have been cut in Unit A of the formation, some being close to the contact with the underlying Esna Shales. This sharp lithologic interface is at the origin of major geotechnical problems (Curtis and Rutherford, 1981; Aubry et al., 2015). In contrast, the lithologic homogeneity of Unit A of the Thebes Limestone explains well the good preservation of many royal tombs. The lithologic log of the Thebes

Limestone Formation (Fig. 8) will be particularly valuable for archeological research in the Necropolis of Sheikh Abdel Gurnah which is famous for its beautiful tombs of the Nobles. It is beyond the scope of this paper to discuss the potential of our detailed log in solving geoarcheological problems in this displaced structural block where most tombs have been cut in lithological Units B to G. However, we emphasize that their lithological subunits can be readily delineated in the block with an average stratigraphic (vertical) precision of 7 m. This has allowed precise location of the tombs in the regional lithologic context and estimates of the impact of the quality of the embedding rock on the choice of their location by the Pharaonic builders (Karlshausen and Dupuis, 2015). The methodology can now be regionally extended to the whole of the Theban Mountain and provides a framework for a comprehensive effort in the preservation and management of the magnificent Theban monuments.

XI- Conclusions

Our revision of the Thebes Formation (sensu Said 1960) at its stratotype locality of Gebel Gurnah provides a high-resolution record of lithologic variations over the 338 m thick section. We place the Thebes Formation in a sequence stratigraphic context and in a temporal framework of bioclastic deposition during the EECO (Early Eocene Climatic Optimum). The Formation in its type locality represents ~ 2.8 Myr of Early Eocene deposition spanning Biochrons NP12 to NP13 and E5 to E6. The combined use of biostratigraphy and sequence stratigraphy allows a comprehensive interpretation of the section and a preliminary placement in a global chronostratigraphic framework.

From the base (0 m) of lithologic Unit A to the uppermost *Turkostrea* coquina beds at the top (338 m), the sedimentary succession at Gebel Gurnah comprises six depositional sequences with sequence boundaries (SB) marked by the tops of six nodular limestone beds: at 93.5 m (NLA), 199.8 m (LNE), 212.6 m (LNG), 290 m (LNJ) and 326 m (LNL). The SB between Sequence Thebes 5 and Minia 1 is marked by a *Turkostrea* coquina (Unit M; base of Sequence Minia 1) overlying a nodular limestone (LNL at top of sequence Thebes 5) and it constitutes a major stratigraphic marker in the section. These *Turkostrea* coquinas are the shallowest HST deposits encountered directly above a SB in the section, indicating that this SB results from a more pronounced sea level drop than any of the four older sequence boundaries in the section. Based on this, its widespread occurrence in Egypt (Snavely et al., 1979) and its biostratigraphic position (lower Zone NP13 at 232 m), we identify this SB as reflecting the major late Early

Eocene sea level fall of Yp10 (Neal and Hardenbol, 1998). Based on this, our sequence stratigraphic description of the section is easily matches with the global record of five stratigraphic sequences below Yp10 (Neal and Hardenbol, 1998), with Thebes 1 assigned to Zones NP12 and E5, and the TST fine-grained limestones of Thebes-4 assigned to lower Zone NP13 (Fig. 19). This allows us, in turn, to equate the four older SBs between 93.5 m and 290 m with SB Yp9 to SB Yp6 of global sequence stratigraphy, although we identify difficulties with straight correlation between the Thebes and global sequences. We have emended the definition of the Thebes Formation, whose top was not distinguished as a contact with an overlying formation, by proposing that the major SB between Sequences Thebes 5 and Minia 1 constitutes a distinctive and reliable lithologic marker. As emended, the Thebes Formation is comprised of five sedimentary sequences (Thebes 1 to Thebes 5) and is sharply delineated from the underlying Esna Shale Formation and the overlying Minia Limestone Formation (Unit M, Sequence Minia 1). In recognition of this emendation we adopt the name Thebes Limestone Formation proposed by El Naggar (1966).

The temporal extent of the Thebes Limestone Formation is ~2.8 Myr between <52.45 Ma for the base of the formation which marks the definitive establishment of an almost pure carbonate regime, and ~49.6 Ma when a major eustatic event occurred, resulting in widespread signatures in regional stratigraphies as recognized by Vail et al. (1977). The sharp formational contact between the Esna Shale and the Thebes Limestone (reference level 0 m in this study) does not register an abrupt regime change, but the ultimate establishment of a bioclastic regime under high subsidence rates. The interfingering of limestone stringers in the shales of the Qurnah Calcareous Shale Member indicates unstable conditions and progressive regime change, as is well documented by clay mineralogy. Dominantly carbonate (and with strongly reduced detrital influx) deposition in the area now called Gebel Gurnah occurred on a very wide, actively and steadily subsiding shelf, at probably >100 km from the continent. The accumulation rates have clearly varied considerably between sequences as well as within each sequence, but an approximate, average accumulation rate of 11.5 cm/kyr can be estimated for the Thebes Limestone Formation (between the base of Unit A at ~52.45 Ma and the top of NLL at 326 m at 49.6 Ma), which is high for a carbonate bioclastic deposit. We interpret this as resulting from the combined effect of high productivity during the EECO and high regional subsidence rates despite sustained decrease in sea level at least between 52.45 and 51 Ma. We propose that the Thebes Limestone Formation is a testimony to tectonic relaxation following intense tectonic activity of the Syrian Arc folds, and reflects a change in sedimentary regime, from predominantly detrital deposition (Esna Shale Formation) at rates of ~9 cm/kyr (as estimated in the Dababiya area), to predominantly bioclastic deposition (Thebes Limestone Formation) on a neritic shelf at rates >10 cm/kyr (as estimated in the Thebes area). In conclusion, the rapidly deposited Thebes Limestone Formation provides an example of high productivity on an actively subsiding tropical carbonate platform during the EECO.

Addendum (M-P. Aubry and C. Dupuis)

The widely used name *Esna Shale* has been controversial in the lithostratigraphic classification of sedimentary rocks in Egypt. To remedy this, El Naggar (1965) defined an "Esna Group" that he subdivided into the Cretaceous Sharawna Formation and the Paleocene Owaina Shale Formation. He then subdivided the latter into three members, Lower Owaina Shale, Middle Owaina Chalk and Upper Owaina Shale. The latter extended to the Thebes Calcareous Shale below the Thebes Limestone proper (op. cit., fig. 3) both of which he subsequently (1970) assigned to the Libyan Desert Group. Simultaneously, he (op. cit., p. 6) renamed the Thebes Calcareous Shale as the "Qurnah Calcareous Shale".

However, a parallel lithostratigraphic framework had developed in Egypt, in which the Middle Owaina Chalk Member was called the Tarawan Formation (Awad and Ghobrial, 1965) and the Lower Owaina Shale Member was part of the Dakhla Formation (Awad and Ghobrial, 1965) (see Hermina, 1990). Introduction of these two lithostratigraphic units allowed restriction of the Esna Formation to the lithostratigraphic interval between the Tarawan Formation and the Thebes Group (introduced by Hermina, 1990, p. 284, in replacement of the Thebes Formation of Said, 1962). Said defined the base of the Thebes Formation as corresponding to the base of the Thebes Limestone, which implied that the Esna Formation extended from the top of the Tarawan Chalk to the base of the Thebes Limestone sensu stricto. In turn this means that the "Qurnah Calcareous Shale" of El Naggar (1970) belongs to the upper part of the Esna Formation sensu Hermina (1990) not to the Thebes Group.

In our studies on the Upper Paleocene-Lower Eocene in the Nile Valley, we have adopted Hermina's lithostratigraphic framework, although we have slightly modified the names of the formations, in particular replacing the name Esna Formation by Esna Shale Formation. We have also subdivided this formation based on the presence of five characteristic beds that occur in its lower part and exhibit a considerable lateral extension across Egypt, recognizing at the same time the characteristically more calcareous nature of its upper part. These subdivisions, initially informally named (Esna 1, Dababiya Quarry beds, Esna 2, Esna 3; Dupuis et al., 2003), were formally introduced as members named from the localities where they are best represented in the Upper Nile Valley. These are, in stratigraphic order, the Hanadi Member, Dababyia Quarry Member, El Mahmyia Member and Abu Had Member. The latter member corresponds to the upper part of the Esna Shale Formation characterized by alternating stringers of shales and calcareous shales, and it was named after Gebel Abu Had where it is particularly well represented. However, the renaming of Esna 3 as the Abu Had Member was based on miscorrelation of the Esna 3 with the Abu Had Member of El Razik (1972) which designates the lower member of the Thebes Formation (referred herein as Lithologic Unit A). We correct this unfortunate error here by adopting the name of "Qurnah Calcareous Shale" of El Naggar (1970). Thus, the name Abu Had Member of the Esna Shale Formation as introduced by Aubry et al. (2007, table 1, p. 277) is formally renamed here the *Qurnah Calcareous Shale Member*, this name substitution being in agreement with the lithostratigraphic framework of Hermina (1990). As its name indicates, the type locality of this member is at Gebel Gurnah where it outcrops majestically behind the temple of Deir Bahari and below Lithologic Unit A of the Thebes Limestone Formation. The Qurnah Calcareous Shale Member is also well exposed in the Dababya Quarry to the South and at the edge of the Eastern Desert. It is 43.5 m thick in the Dababiya quarry. Note that we retain the original name and orthography of Qurnah [rather than Gurnah] of El Naggar.

*Note: we use here subseries and subepoch in a formal sense in agreement with the argument presented by Aubry (2016).

Responsibilities. This paper is based on a preliminary draft manuscript dated June 2013 which our colleague Chris King prepared on behalf of the authors of this paper. Unfortunately Chris passed away unexpectedly in January 2015, and the completion of the manuscript was left in our hands. The preparatory fieldwork was conducted by C. Dupuis; measurement was done by him and W. Fathi; logging was conducted by C. King, R. Knox and C. Dupuis. Biostratigraphic analysis on planktonic foraminifera was conducted by W.A. Berggren and on nannofossils by M-P Aubry. P/B ratio and paleobathymetric interpretation were made by C. King. Mineralogy (whole rock and clay mineralogy) was conducted by C. Dupuis and J-M Beale. C. Dupuis updated the sequence stratigraphic framework by C. King, and M-P Aubry correlated it to global stratigraphy. With one exception, all field photographs were prepared by C. Dupuis. The final versions of all illustrations for this paper were completed by C. Dupuis. M-P Aubry is primarily responsible for the organization and writing of the finished version of this manuscript, assisted by W.A. Berggren and C. Dupuis. Appendix 1 was prepared by C. King and Appendices 2 to 4 by W.A. Berggren.

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Figure captions

Figure 1. Location of the Gebel Gurnah section (inset) opposite the Nile River near Luxor, Upper Egypt. The highest point corresponds to El Qurn that is ~370 m above sea level. MH: Temple of Medineh Abu; R: Ramesseum; TH: Temple of Hatshepsut at Deir El Bahari; TS: Temple of Seti 1^{st}, VK: Valley of the Kings; VQ: Valley of the Queens.

Figure 2. Extension of the Thebes Formation and other correlative formations (Thebes Group; see Appendix 1) in Egypt. Note the broad distribution of the group over the stable shelf. The boundary between the stable and unstable shelf is approximated based on Höntzsch et al. (2011). B: Baharya Oasis; D: Dakhla Oasis.

Figure 3. Gebel Gurnah as seen from Luxor on the east bank across the Nile River. Note the prominent horizontal stratification enhanced by overhanging cliffs.
From South to North: VQ: Valley of the Queens, DEM: Hill of Deir El Medineh; QM: Hill of Qurnet Mura'ï; SAG: Sheikh Abdel Gurnah; DEB: Amphitheater of Deir el Bahari; DAN: Dra Abu Naga.

Figure 4. Lithologic subdivisions proposed by successive authors for the Thebes Formation at Gebel Gurnah.

Figure 5. Location of the partial sections of the composite section along which the Thebes Limestone Formation at Gebel Gurnah was logged and sampled. The partial sections were set in carefully selected outcrops. NF: North Face of Gebel Gurnah; EF: East Face; SF: South Face.

Figure 6a. Field location of the partial sections along the composite section.
A (above): sections ELQX, ELQA and ELQB and their relationship to the cliffs. The junction of sections ELQX and ELQA is at the top of Cliff 2, and that of ELQA and ELQB at the top of Cliff 3; ELQB extends to the top Cliff 5. Note the "Village du repos" located between the Village of Deir El Medineh and the Valley of the Kings, where the workers of the necropolis rested at midday. This village lies on the pink marls of Subunit C3 over the very broad ledge of Cliff 2. The base of partial section ELQX is located at the entrance of Tomb VK 39 (unidentified tomb of the 18^{th} Dynasty).

B (below): Northwest face of the Sheikh Abdel Gurnah tilted block with SAG partial section from Subunit C1 (purple marl) to NLG and Cliff 4. MMA 1113–1115 denote entrances to tombs cut in the Thebes Limestone Formation (and studied by the Massachusetts Museum of Fine Arts).

Figure 6b. Field location of the partial sections along the composite section (continued).
C (top left): ELQC: from NLG to the top of Unit M (at top of the composite section; = top of El Qurn)
D (bottom left): VKA from the top of Unit A to Subunit B5
E (right): WOB in the top of the Esna Shale (Gurnah Member) and WOC in Lithologic Unit A.

Figure 7. Correlation between the partial sections and relations between the cliffs and the main lithologic landmarks. Yellow: nodular limestone; pink and purple: marls.

Figure 8. Detail log of the composite section of Gebel Gurnah.
8a. Lithologic description between 0 m and 60 m (Subunit A1 to A4)
8b. Lithologic description between 60 m and 125 m (Subunit A4 to Subunit B6)
8c. Lithologic description between 125 m to 190 m (Subunit B6 to Subunit D4)
8d. Lithologic description between 190 m to 250 m (Subunit E1 to Subunit I1)
8e. Lithologic description between 250 m to 310 m (Subunit I1 to Unit K)
8f. Lithologic description between 310 m to 340 m (Unit K to Unit M), and key to lithologic, paleontologic and sedimentologic symbols.
Note: we provisionally retain the name '*Lucina thebaïca*" for the large molluscs that occur commonly in the Thebes Limestone Formation from the top of Unit A up to Subunit D3 (81.50–186 m). The name *Anondotia hatshepsutae* has been introduced for the older specimens (Strougo, 1996), but we have no field observations to differentiate between the two forms.
Red arrows: location of samples analyzed herein.

Figure 9. Examples of lithologic markers exposed on the western side of the necropolis of Sheikh Abdel Gurnah (SAG).

9a: Lithologic Units C1, C2, C3 near Tomb TT29 (the door of the chapel is about 2.40 m high; excavations of the Belgium Mission, Université libre de Bruxelles et Université de Liège, MANT [Mission Archéologique de la Nécropole Thébaine).

9b: Marly beds of Subunit F2 (green) and Subunit F4 (purple) behind the 3rd cliff on the terrace of Tomb TT79; note the base of NLG [upper left] (scale given by the orange compass; its side is 10 cm long).

9c: Yellow marl H2: near the Upper Enclosure (stone wall) to the west of the hills of SAG (note stone-wall in the rear).

9d: Prominent bed J at the base of Cliff 4 overhanging Subunit I2, in which the tomb MMA1120 was excavated: western summit of the hill of SAG; the necropolis extends downwards to the right (the prominent bed is ~1 m-thick).

Figure 10. Examples of characteristic lithologies encountered in outcrops along the Gebel Gurnah composite section.

10a: Compact limestone with rare, thin, irregular flint layers (arrows): WOC partial section, Subunit A4, 71 m.

10b: “Marble” limestone with cm-size rounded flint (f) and their imprints (e): Sheikh Abdel Gurnah necropolis, TT96, Subunit C4a, ~ 145 m.

10c: Limestone with burrow-filled concretions (arrows): Sheikh Abdel Gurnah necropolis (SAG), TT65, Subunit Cab, ~ 160 m.

10d: Phosphatic limestone with cm-size phosphate-coated pebbles (p) and smaller dark phosphate grains (g): WOC partial section, Subunit B1, 93.94 m.

10e: Contact between the bioclastic limestone D4 and the nodular limestone NLE (Subunit E1): ELQA partial section, 190 m (photograph CK).

10f: Numerous irregular cm-thin flint layers in the compact limestone of Subunit A3: WOC partial section, ~ 70 m (the outcrop is 3 m high).

10g: Closer view of the flints of Subunit A at 19 m. Flints tend to be tabular and longer than 30-40 cm (1), although some remain shorter (2). Note the shape in (3) which is a section of a torn-shaped flint concretion. Such concretions are regionally frequent.

10h: Limestone (light brown) with semi-tabular flint layers (grey) about 1 m-long, Subunit H3: SAG, ~ 232 m, near TT91. The pen (for scale) is 15 cm long.

Figure 11. Lithologic succession in relation to the cliffs at Gebel Gurnah. Lithologic marker beds are identified in Fig. 8. P/E = Paleocene/Eocene boundary. PETM= Paleocene-Eocene Thermal Maximum.

Figure 12. Distribution of paleontologic and micropaleontologic groups in the Thebes Formation along the Gebel Gurnah section, and biozonal ages based on planktonic microfossils. Asterisk denotes indirect/secondary correlation with standard biozonation. See Figure 16 (below) and Appendix 4 for further explanation of Lower Eocene planktonic foraminiferal biostratigraphy of the section.

Figure 13. Paleoenvironmental interpretation of the main lithofacies encountered in the Thebes Formation and inferred from the association of lithologic and paleontologic characters.

Figure 14. Whole rock and clay mineralogy of the Thebes Formation in the Gebel Gurnah–Sheikh Abdel Gurnah composite section.

Figure 15. Depositional sequences in the Thebes Formation as recorded in the Gebel Gurnah section. Note the general upward shallowing trend superimposed on the short term shallowing within each sequence.

Figure 16. Comparison and correlation of ranges of main species of planktonic and larger benthic foraminifera in the Thebes Formation at Gebel Gurnah in Hamam (1971) and this paper.

The base of the Thebes Formation is located within lower Zone E5/P7 (with an estimated age of 52.2 Ma). Scattered *M. aragonensis* occur as high as 244 m. The boundary between Zone NP12 and NP13 lies within the ~ 78 m interval between 178 m and 232 m. The NP12/NP13 boundary lies within the biostratigraphic interval of (PF) Zone E6/P8 with an estimated duration of 0.4 Myr between 50.8 and 50.4 Ma (BKSA95, BP05, WPBP11). We can thus bracket the uncertainty interval (~178 m and 232 m) of the NP12/NP13 zonal boundary at Gebel Gurnah with/by the uncertainty interval of (PF) Zone E6/P8 (shown here and in Fig. 16 in parenthesis; denoted by asterisk). Thus, we can estimate that this lithostratigraphic interval encompasses the interval between ~50.8-50.4 Ma of the Early Eocene.

The shaded zones indicate the intervals of reliable lithological correlations. Note that the top of the Thebes Formation is recorded at 450 m in Hamam (1971), and at ~ 348 m in this paper. The base of this formation in this paper as at 0 m whereas it is at 46 m in Hamam. Hamam studied 46 m of Esna Shale below (essentially Qurnah Calcareous Shale Member), which we did not study here. Thus the total thickness of the Thebes Formation in Hamam would be ~ 40 m, leaving a discrepancy of about 50 m between the two studies. We ascribe the difference in thickness in these two studies to the fact that the Gebel Gurnah section in our study was measured with a Jacob staff. Our values are supported by the fact that the section was measured independently by two members (CD and CK) of our group with virtually similar results. E.S.: Esna Shales.

Figure 17. Comparative distribution of selected, biostratigraphically significant calcareous nannofossil species in the Thebes Formation at Gebel Gurnah as reported in five different studies. Note the good overlap of species occurrences in these studies. Although not shown, it is worth mentioning that Boukhary and Abdelmalik (1983) reported the presence of *Heliodiscoaster lodoensis* and *H. sublodoensis* in assemblages from outcrops of the Thebes Formation between Cairo and Luxor, although without details on the precise occurrences of the two species, which would possibly confer a biozonal assignment to lower Zone NP14 (Subzone NP14a of Aubry, 1995) to at least part of the formation. This is clearly incompatible with their "early Early Eocene (Ypresian s. st." age determination of the formation, their record of planktonic foraminifera as well as ours, and the occurrence of *Heliodiscoaster cruciformis* as reported here.

Figure 18. Lithostratigraphic divisions into three members of the Thebes Limestone Formation in the Central/Upper Nile Valley and Eastern Desert by Snaveyli et al. (1979, Figs. 2 and 3; redrawn and colored here, and with our own identification of the nodular beds). These two logs represent a simplified, synthetic description of the lithologic succession through the Thebes Formation in two areas, central Nile Valley (left) and Eastern Desert (Sea Coast area; right). They are not representation of a specific measured succession in either area. The salient feature in these diagrammatic logs is the subdivision of the formation into three members and the presence of four prominent intervals of nodular limestone in the middle member. Snavely et al. (1979) indicate that the lower member is 135 m thick at Gebel Gurnah, and show (in their figure 2) that the base of lower nodular bed occurs at the contact between the lower and middle members, which corresponds to the lower part of

Subunit C2 in our log (Fig. 8c) whereas the base of (our) nodular limestone bed NLE is at 190 m. Snavely et al. state that the section is 300 m thick vs 338 m herein. Thus the discrepancy between the location of the lower nodular bed (of the middle member) in their log and in ours is probably irrelevant in comparison with the significance of this bed. The simple fact that Snavely et al. illustrate four nodular beds in both the Central/Upper Nile Valley and the Red Sea Coast, just as we have recorded at Gebel Gurnah, should not be seen as coincidental. Rather there is sufficient reason to accept correspondence between their nodular beds with ours. This, in turn, confirms equivalence between, on the one hand, the uppermost nodular bed (of the middle member) and the upper member (Snavely et al.) and, on the other hand, nodular bed NLL and Unit M (this work). We note that Snavely et al. did not show nodular bed NLA in their logs. This is a single nodular bed in a >100 m thick succession which we have measured to be only 20 cm-thick, compared with 10 m thick NLE, and clearly it was not given much importance.

Figure 19. **The Thebes Limestone Formation in a global chronologic framework.** The six sequences of the Thebes Formation (sensu Said, 1960) and their boundaries are located in the global framework of global sequences of Neal and Hardenbol (1998) correlated to the framework of magnetobiochronology in Gradstein et al. (2012). The sea level history is from Miller et al. (2015, unpublished and based on Kominz et al., 2008; for this reason we have used here Time Scale Maker v. 6.8 rather than the update of v. 7.1 which is based on Ogg et al. 2016). The definition of the Thebes Formation is emended to delineate the top of the Thebes Limestone Formation at level 326 m at the top of nodular limestone bed L (NLL) identified as SB Yp10 of global sequence stratigraphy. Consequently the sequences are renamed, the youngest one belonging to the base of the overlying Minia Limestone Formation. The asterix in Sequence Thebes 4 shows the approximate position of level 232 m with an NP13 zonal age.

Table captions

Table 1. Lithostratigraphic subdivisions of the Lower Eocene succession at Gebel Gurnah, as reported in biostratigraphic studies that included calcareous nannofossils. The divisions used in Perch-Nielsen et al. (1978) were based on El-Naggar (1971) which were derived from El-Naggar (1966). The Qurnah Calcareous Shale Member is the "Thebes Calcareous Shale Member of El-Naggar (1966) and Hamam (1971). The lithologic subdivisions of the Thebes in Tawfik et al. (2011) are those of Curtis (1977). Note that the orthography of lithologic units follows original publication.

Table 2. Whole rock and clay mineralogy of the Thebes Formation.

Table 3. Planktonic foraminiferal biostratigraphic framework and biochronology of (that part of) the Lower Eocene relevant to Gebel Gurnah. Author abbreviations: BM88=Berggren and Miller (1988); BKSA95= Berggren, Kent, Swisher and Aubry (1995); BP05, BP06= Berggren and Pearson, (2005); Berggren and Pearson (2006). Zonal abbreviations: LOZ= Lowest Occurrence Zone; PRZ=Partial-range Zone; CRZ=Concurrent-range Zone

Table 4. Evaluation of planktonic foraminifera identified in Keheila et al. (1990) in sections 5 and 6 near Nag Hammadi, south of Sohag and west of Qena (Nile Valley, Egypt). Columns 1 and 2: figure numbers and identifications/names given by the authors; column 3 "Description": observations/evaluations made here; column 4 "References": Comparison with correctly identified representatives of these taxa shows that these specimens have nothing to do with (supposedly reworked) Paleocene planktonic foraminifera.

Table 5. Stratigraphic range of planktonic foraminifera in the Thebes Formation at Gebel Gurnah. * indirect/secondary correlation; EB = essentially barren.

Table 6. Stratigraphic range of calcareous nannofossils in the Thebes Formation at Gebel Gurnah.

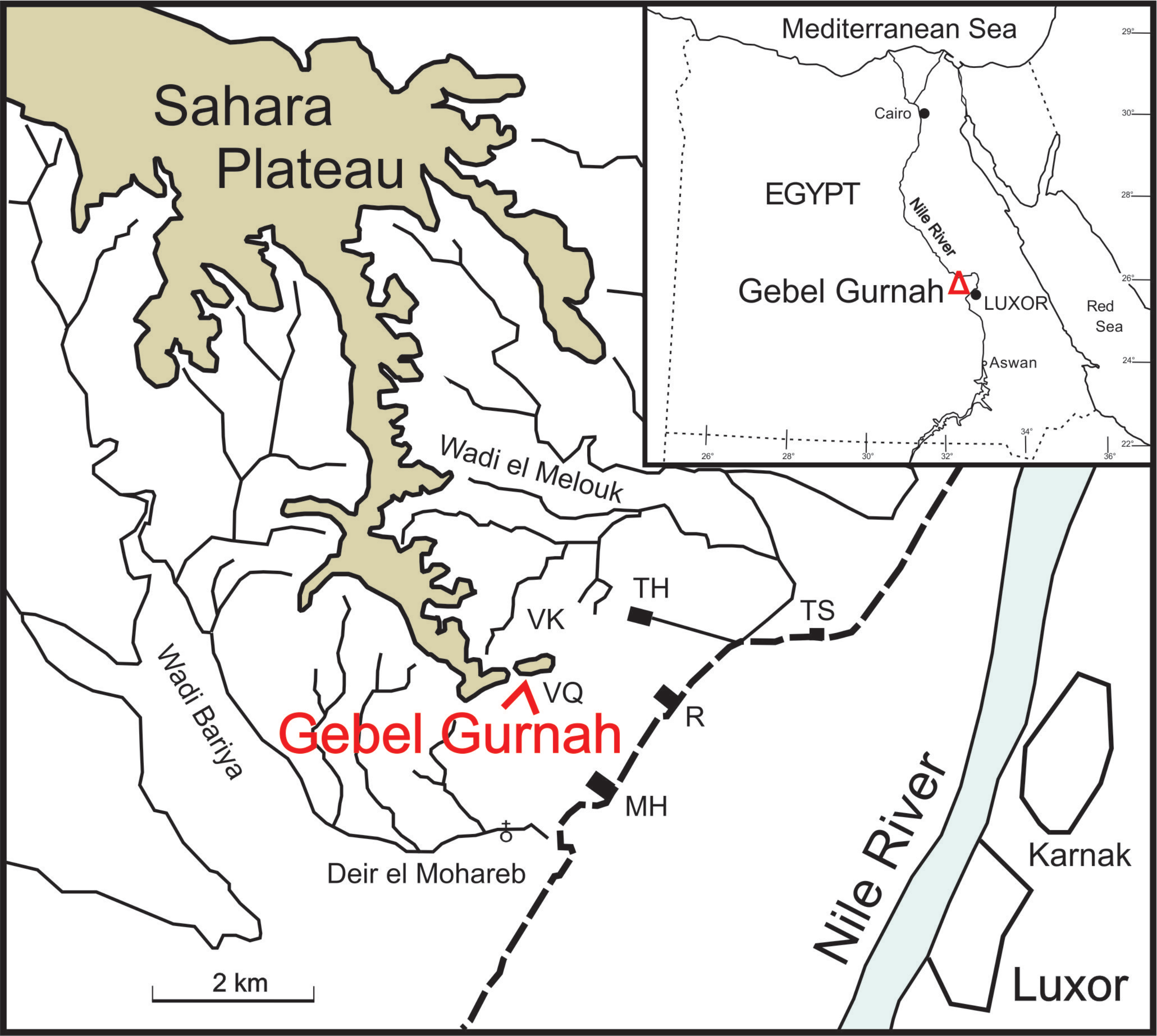
Appendices

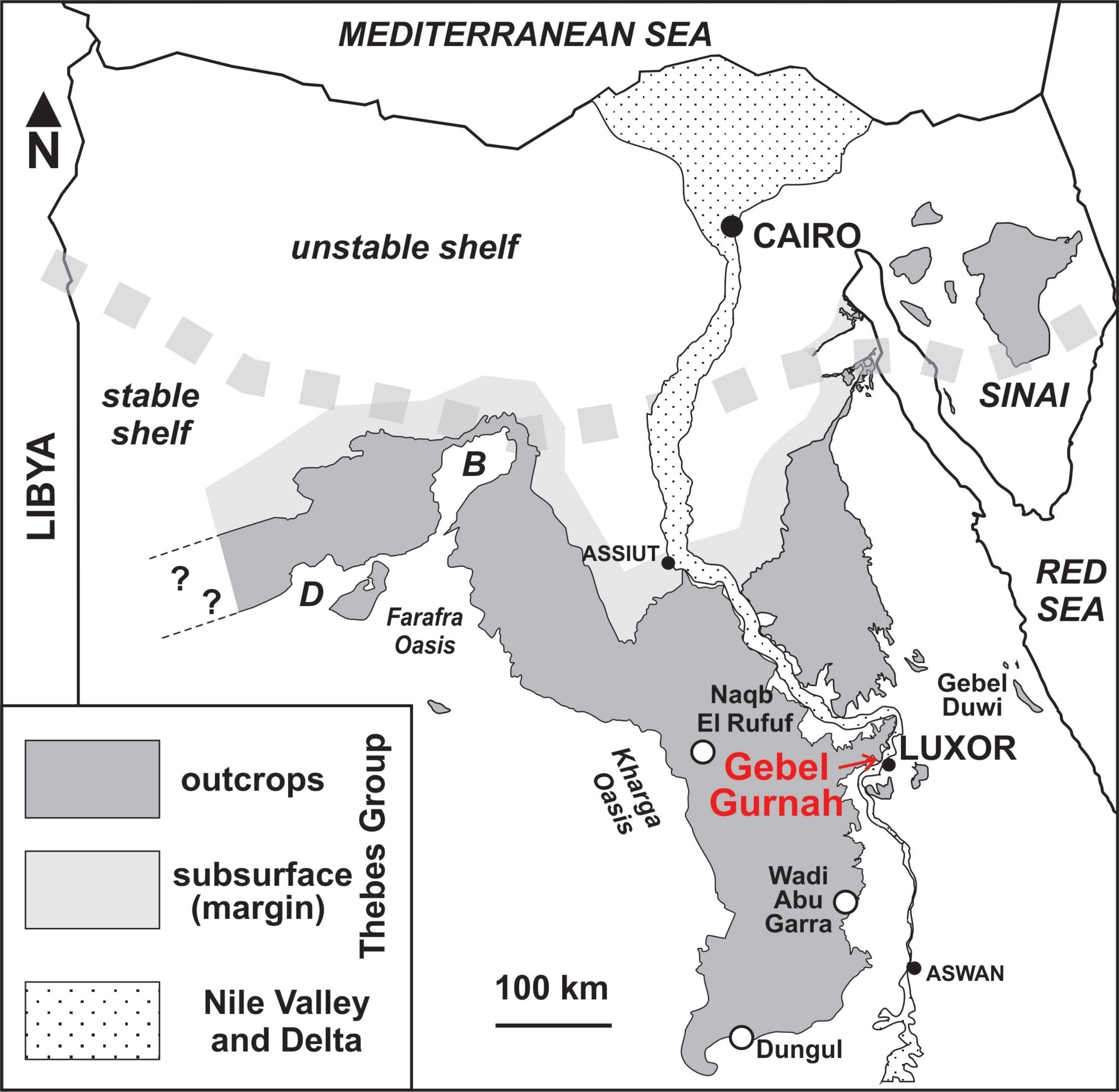
Appendix 1. Lithostratigraphic terminology of the Thebes Group and adjacent units—Historical overview. [Chris King]

Appendix 2. Lateral extension of Lower Eocene Litho- and biostratigraphy from the Upper Nile Valley to the Western Desert (Farafra Oasis section). [W. A. Berggren]

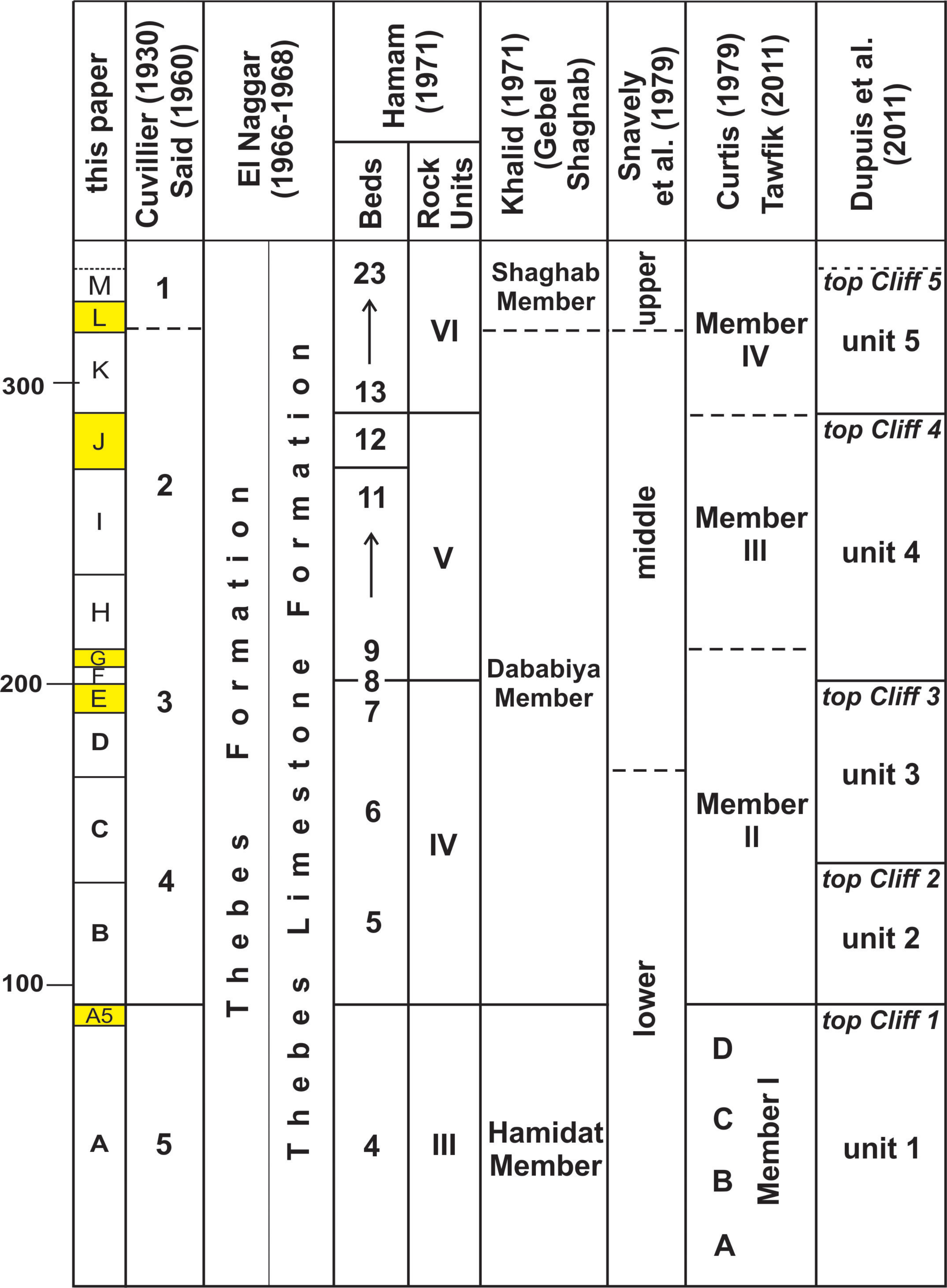
Appendix 3. Review of planktonic and larger benthic foraminifera stratigraphy of the Thebes Limestone Formation [W. A. Berggren]

Appendix 4. Estimated biochronologic framework of the Lower Eocene Thebes Limestone Formation at Gebel Gurnah, Egypt. [W. A. Berggren]

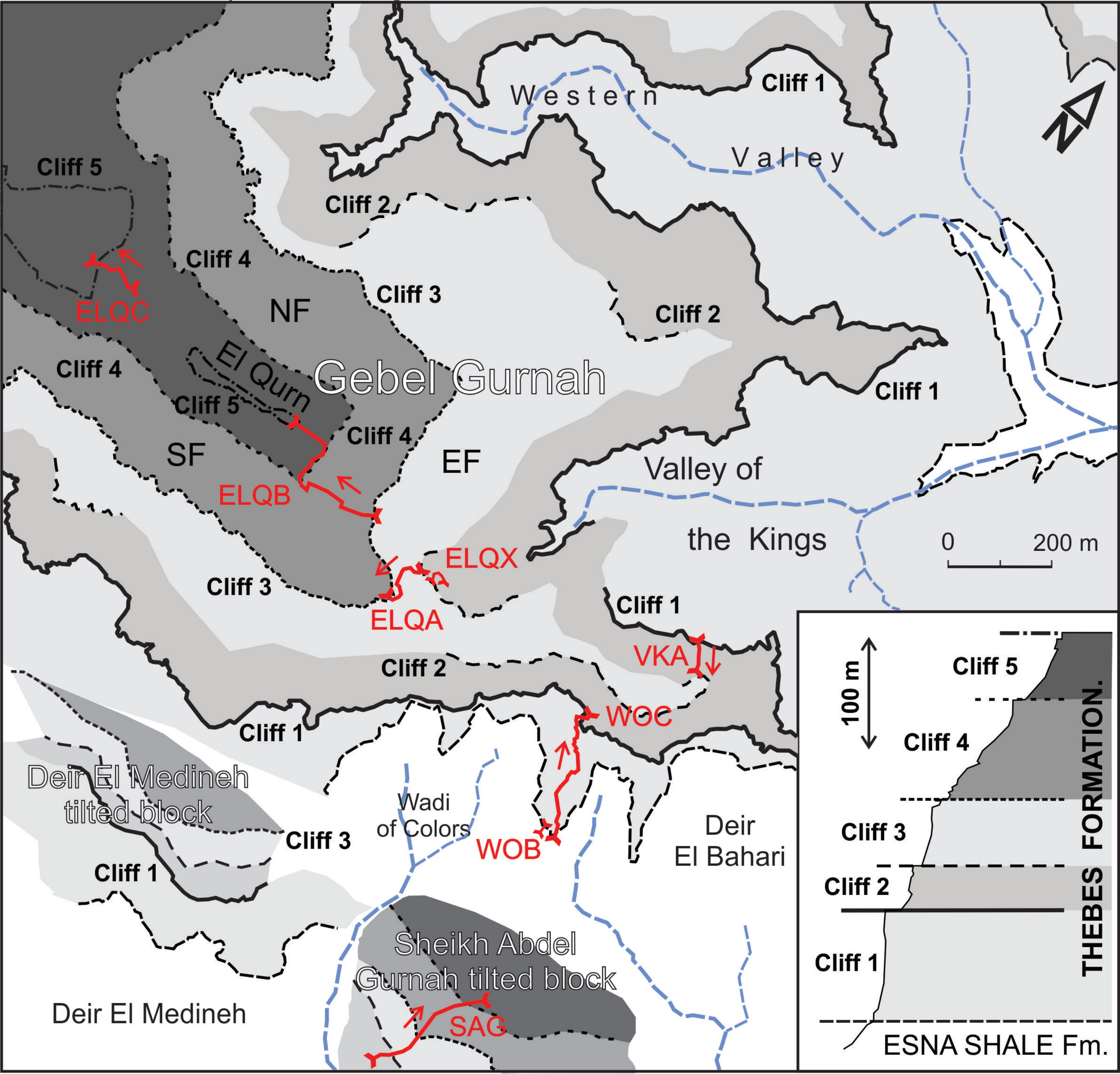

Sahara Plateau
Mediterranean Sea
Cairo
EGYPT
Nile River
Gebel Gurnah
LUXOR
Red Sea
Aswan
29°
30°
28°
26°
24°
22°
26°
28°
30°
32°
34°
36°
Wadi el Melouk
TH
TS
VK
VQ
R
MH
Wadi Bariya
Gebel Gurnah
Deir el Mohareb
Nile River
Karnak
Luxor
2 km


MEDITERRANEAN SEA
N
unstable shelf
CAIRO
stable shelf
LIBYA
SINAI
B
D
?
?
ASSIUT
Farafra Oasis
RED SEA
Gebel Duwi
Naqb El Rufuf
LUXOR
Gebel Gurnah
Kharga Oasis
outcrops
subsurface (margin)
Nile Valley and Delta
Thebes Group
Wadi Abu Garra
ASWAN
100 km
Dungul


S
N
Gebel Gurnah
Cliff 5
Cliff 4
Cliff 3
Cliff 2
Cliff 2
Cliff 1
VQ
DEM
QM
SAG
DEB
DAN
CD 2006

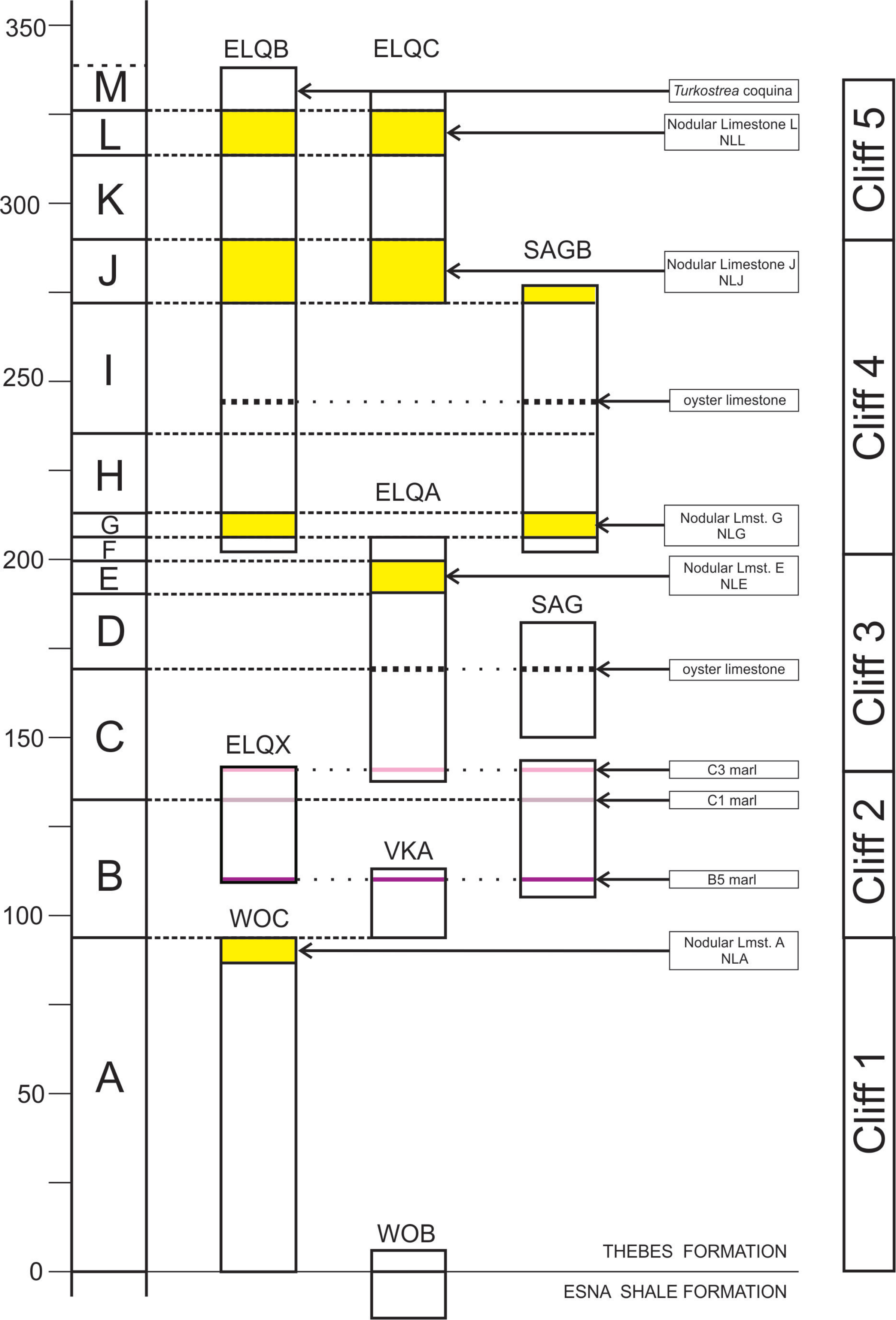


this paper
Cuvillier (1930) Said (1960)
El Naggar (1966-1968)
Hamam (1971)
Beds
Rock Units
Khalid (1971) (Gebel Shaghab)
Snavely et al. (1979)
Curtis (1979) Tawfik (2011)
Dupuis et al. (2011)
300
200
100
M
L
K
J
I
H
G
F
E
D
C
B
A5
A
1
2
3
4
5
Thebes Formation
Thebes Limestone Formation
23
13
12
11
9
8
7
6
5
4
VI
V
IV
III
Shaghab Member
Dababiya Member
Hamidat Member
upper
middle
lower
Member IV
Member III
Member II
Member I
D
C
B
A
top Cliff 5
unit 5
top Cliff 4
unit 4
top Cliff 3
unit 3
top Cliff 2
unit 2
top Cliff 1
unit 1

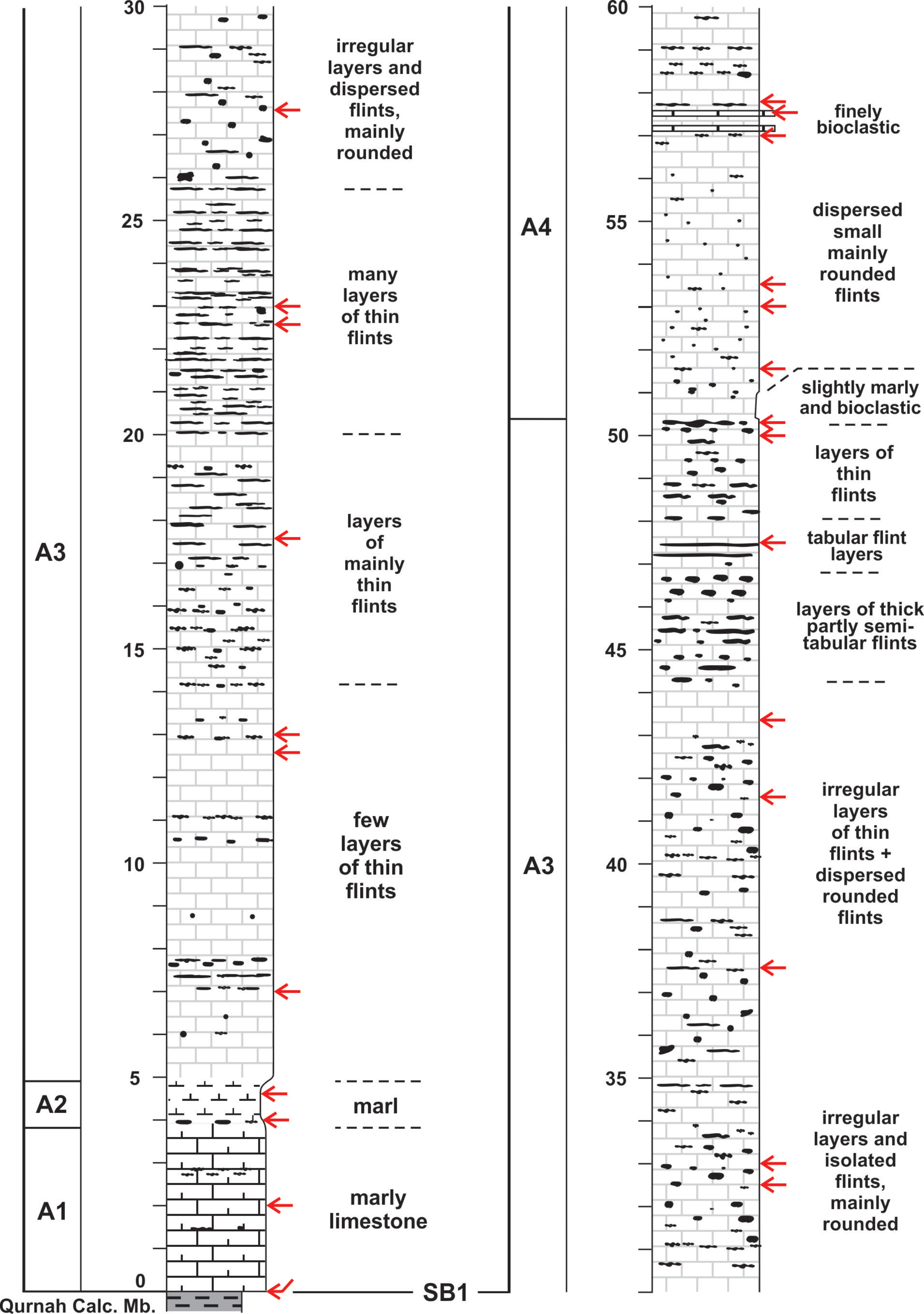

Western
Valley
Cliff 1
Cliff 2
Cliff 5
Cliff 4
Cliff 3
Cliff 2
ELQC
NF
Cliff 4
El Qurn
Gebel Gurnah
Cliff 1
Cliff 5
Cliff 4
SF
EF
Valley of
the Kings
ELQB
0
200 m
ELQX
Cliff 3
ELQA
Cliff 1
VKA
Cliff 2
Cliff 5
100 m
WOC
Cliff 1
Cliff 4
Deir El Medineh
tilted block
Wadi
of Colors
Cliff 3
Cliff 3
WOB
Deir
El Bahari
Cliff 1
Cliff 2
THEBES FORMATION.
Sheikh Abdel
Gurnah tilted block
Cliff 1
Deir El Medineh
SAG
ESNA SHALE Fm.

S
N
top Cliff 5
top Cliff 4
NLJ
ELQB
NLG
NLE
top Cliff 3
ELQA
top Cliff 2
C1 marl
ELQX
VK 39
« village du repos»
towards the Valley of the Kings
a
N
S
top Cliff 4
Upper Enclosure
MMA 1113
MMA 1114
MMA 1115
NLG
top Cliff 3
NLE
SAG
top Cliff 2
C1 marl
b
b

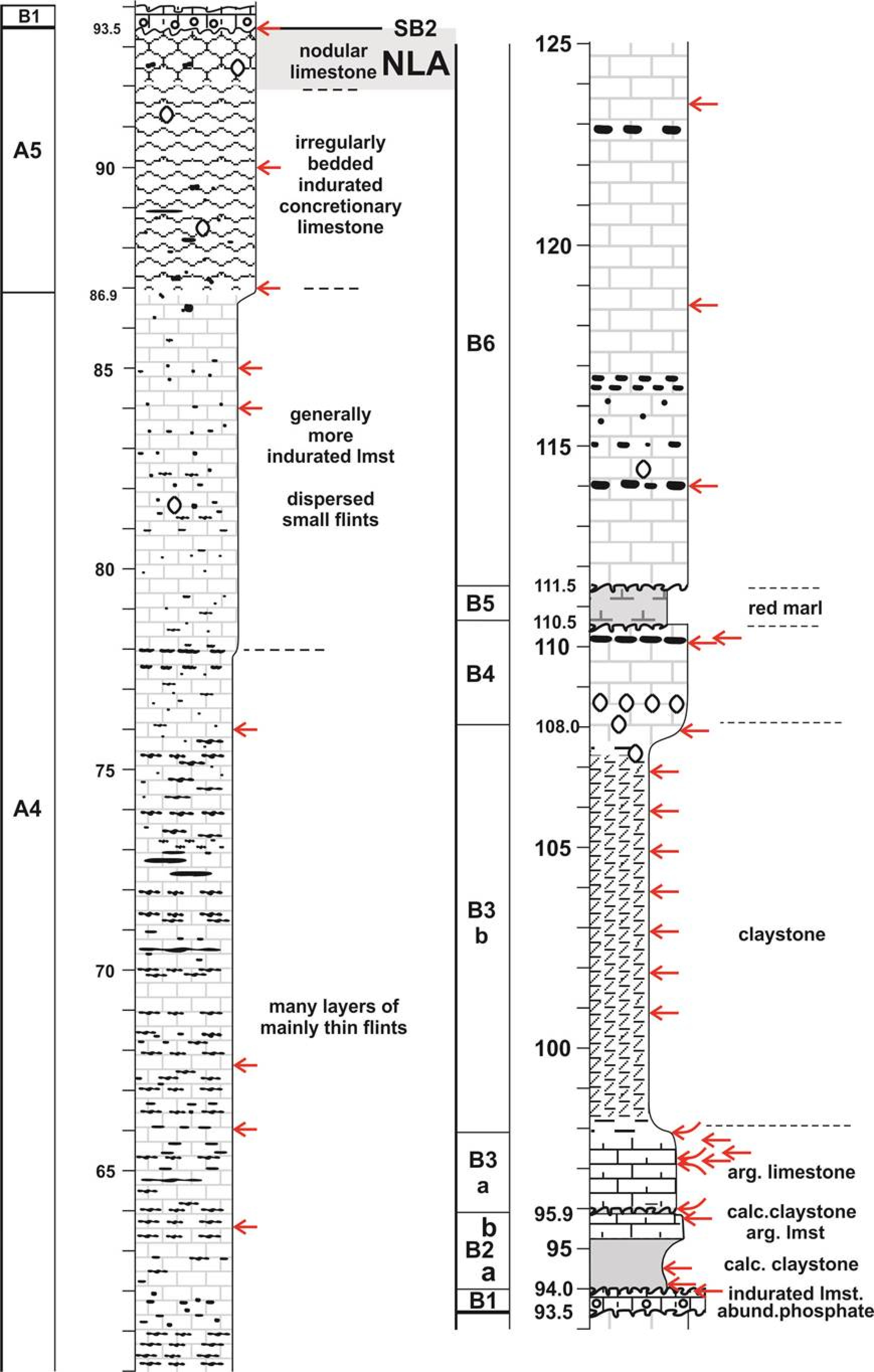

S
N
Unit M
ELQC
NLJ
c
NW
SE
B5 marl
B3b marl
VKA
Valley of the Kings
top Cliff 1
KV 20
d
W
E
top Cliff 1
94m
76m
71m
35m
26m
WOC
19m
A2 marl
MMA 1103
WOB
Thebes Formation (Unit A)
Esna Shale Formation
Qurnah Calcareous Shale Mbr.
e
CD 2007



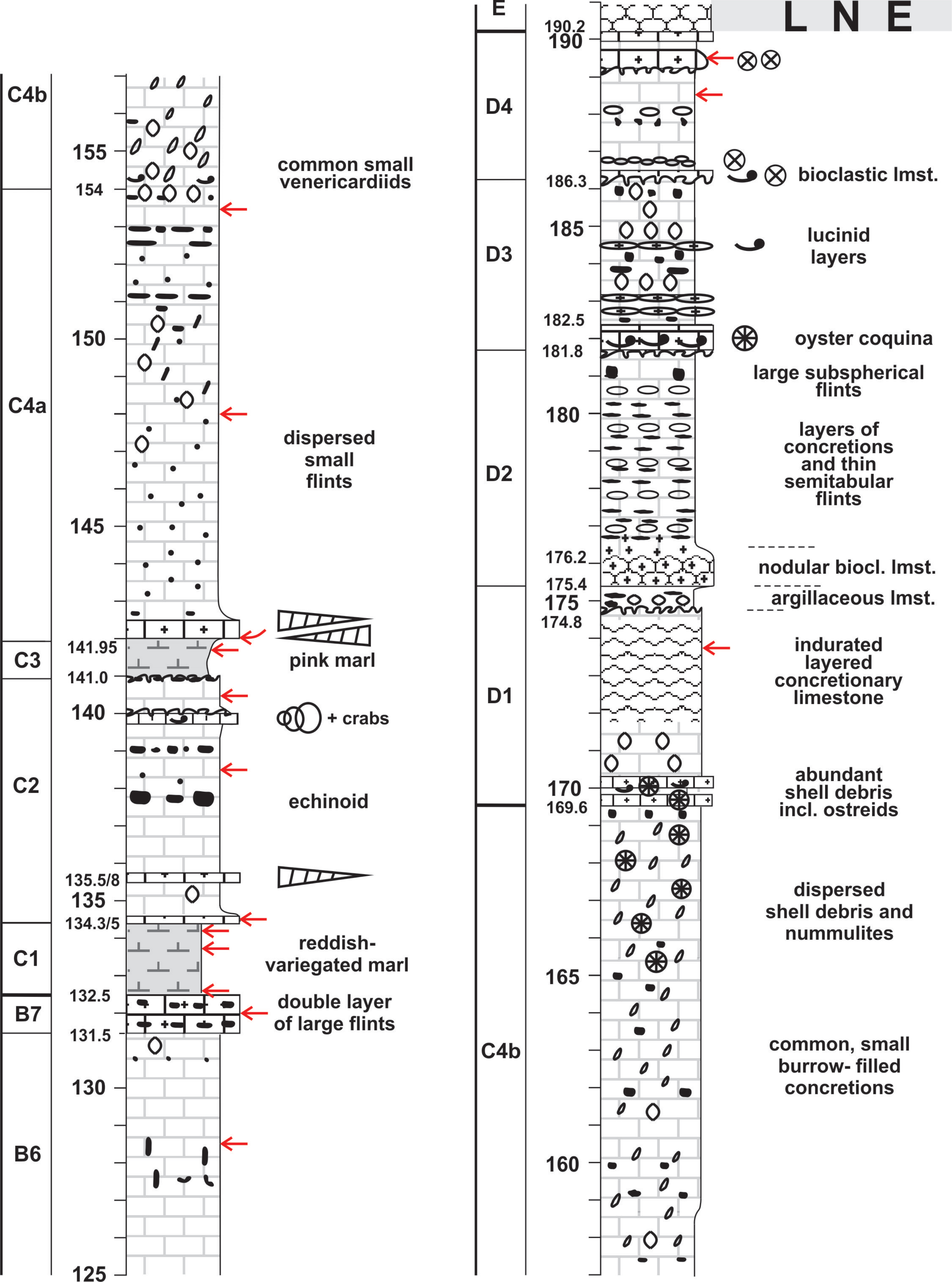
350
300
250
200
150
100
50
0
M
L
K
J
I
H
G
F
E
D
C
B
A
ELQB
ELQC
SAGB
ELQA
SAG
ELQX
VKA
WOC
WOB
Turkostrea coquina
Nodular Limestone L
NLL
Nodular Limestone J
NLJ
oyster limestone
Nodular Lmst. G
NLG
Nodular Lmst. E
NLE
oyster limestone
C3 marl
C1 marl
B5 marl
Nodular Lmst. A
NLA
THEBES FORMATION
ESNA SHALE FORMATION
Cliff 5
Cliff 4
Cliff 3
Cliff 2
Cliff 1



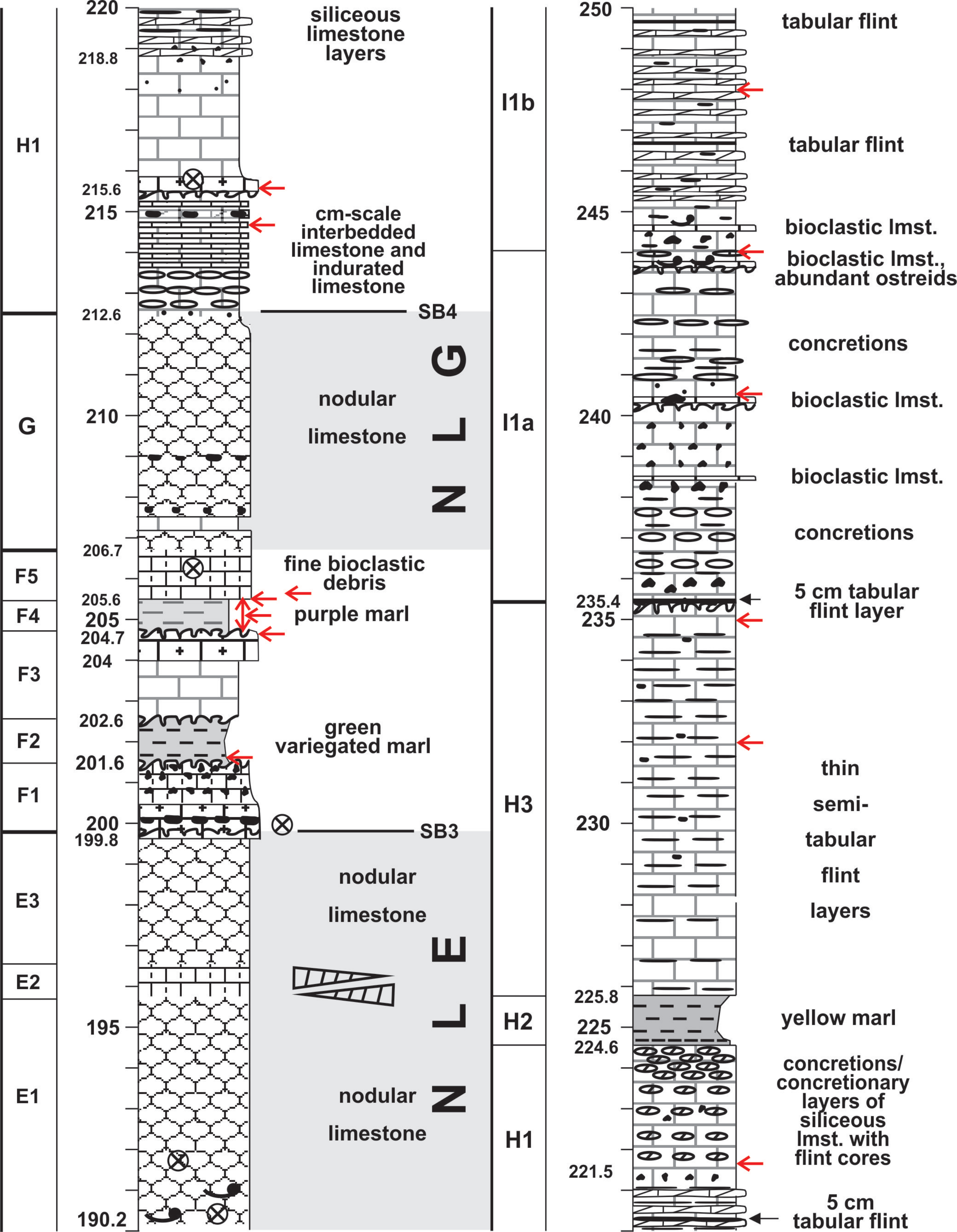
A3
A2
A1
A4
A3
30
25
20
15
10
5
0
60
55
50
45
40
35
irregular layers and dispersed flints, mainly rounded
many layers of thin flints
layers of mainly thin flints
few layers of thin flints
marl
marly limestone
Qurnah Calc. Mb.
SB1
finely bioclastic
dispersed small mainly rounded flints
slightly marly and bioclastic
layers of thin flints
tabular flint layers
layers of thick partly semi-tabular flints
irregular layers of thin flints + dispersed rounded flints
irregular layers and isolated flints, mainly rounded

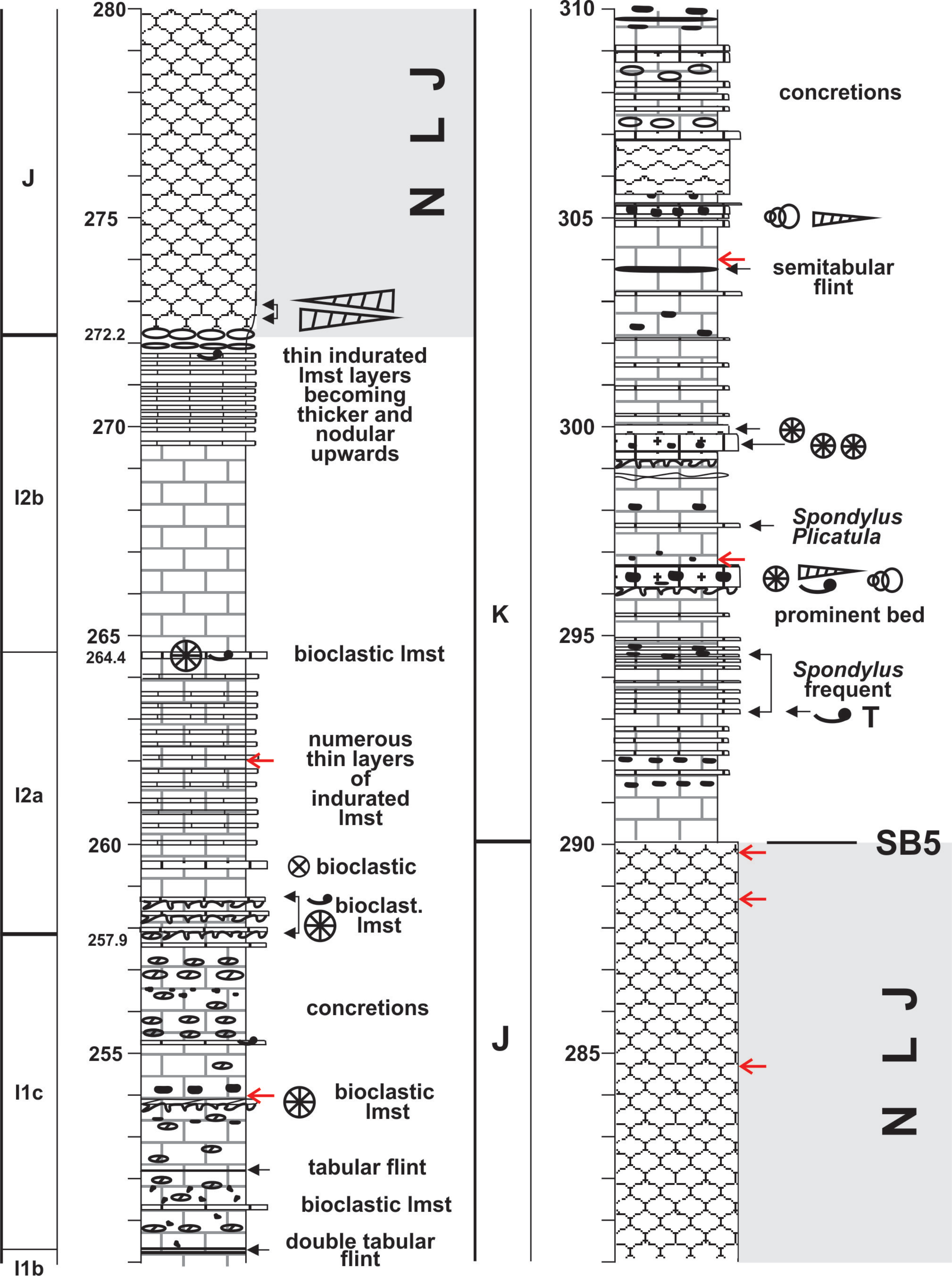


B1
A5
A4
93.5
SB2
nodular limestone
NLA
irregularly bedded indurated concretionary limestone
90
86.9
85
generally more indurated lmst
dispersed small flints
80
75
70
many layers of mainly thin flints
65
B6
B5
B4
B3 b
B3 a
b B2 a
B1
125
120
115
111.5
110.5
110
108.0
105
100
95.9
95
94.0
93.5
red marl
claystone
arg. limestone
calc.claystone arg. lmst
calc. claystone
indurated lmst.
abund.phosphate

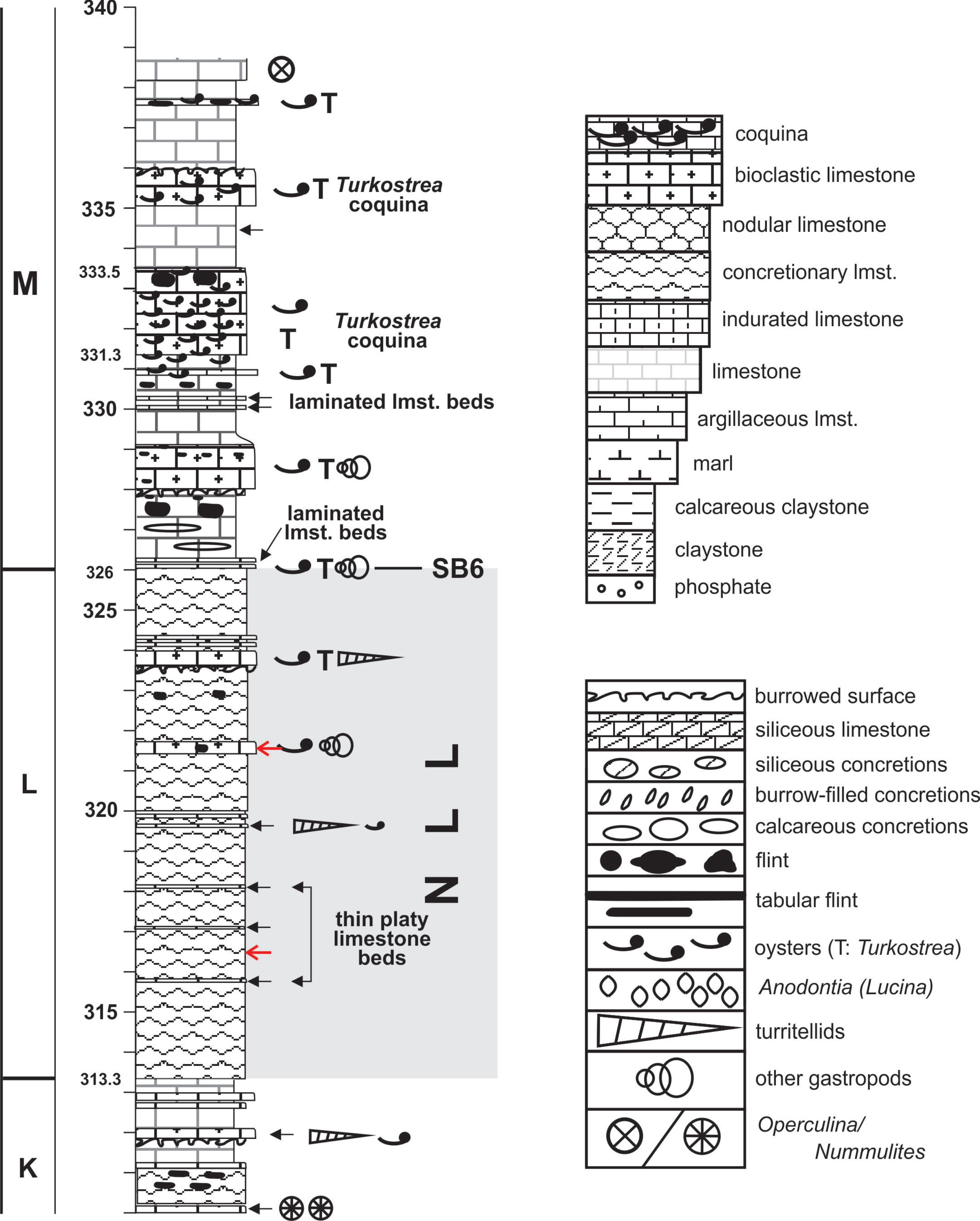


C4b
155
154
common small venericardiids
C4a
150
dispersed small flints
145
141.95
C3
141.0
pink marl
140
+ crabs
C2
echinoid
135.5/8
135
134.3/5
C1
reddish-variegated marl
132.5
B7
double layer of large flints
131.5
130
B6
125
E
L N E
190.2
190
D4
bioclastic lmst.
186.3
185
D3
lucinid layers
182.5
oyster coquina
181.8
large subspherical flints
180
D2
layers of concretions and thin semitabular flints
176.2
nodular biocl. lmst.
175.4
175
argillaceous lmst.
174.8
indurated layered concretionary limestone
D1
170
169.6
abundant shell debris incl. ostreids
dispersed shell debris and nummulites
165
C4b
common, small burrow- filled concretions
160

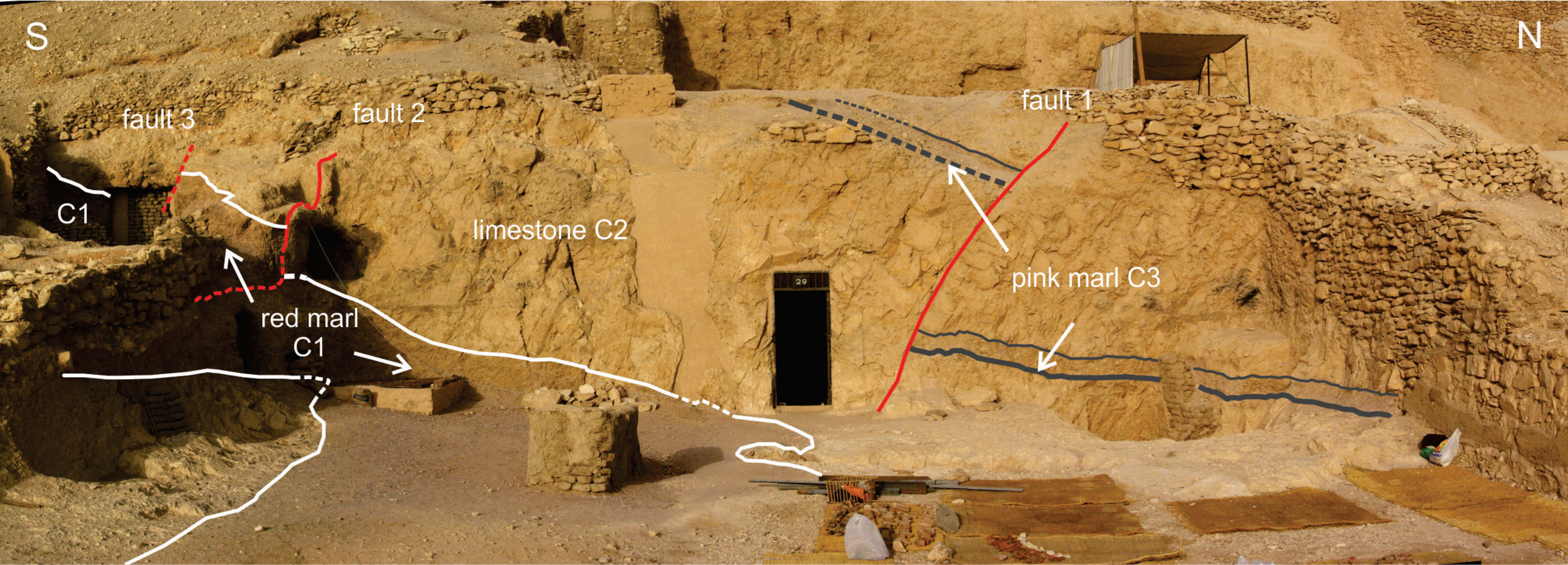

siliceous limestone layers
cm-scale interbedded limestone and indurated limestone
SB4
nodular limestone
N L G
fine bioclastic debris
purple marl
green variegated marl
SB3
nodular limestone
N L E
nodular limestone
H1
G
F5
F4
F3
F2
F1
E3
E2
E1
220
218.8
215.6
215
212.6
210
206.7
205.6
205
204.7
204
202.6
201.6
200
199.8
195
190.2
I1b
I1a
H3
H2
H1
250
245
240
235.4
235
230
225.8
225
224.6
221.5
tabular flint
tabular flint
bioclastic lmst.
bioclastic lmst., abundant ostreids
concretions
bioclastic lmst.
bioclastic lmst.
concretions
5 cm tabular flint layer
thin semi-tabular flint layers
yellow marl
concretions/ concretionary layers of siliceous lmst. with flint cores
5 cm tabular flint



280
275
272.2
270
265
264.4
260
257.9
255
J
I2b
I2a
I1c
I1b
N L J
thin indurated lmst layers becoming thicker and nodular upwards
bioclastic lmst
numerous thin layers of indurated lmst
bioclastic
bioclast. lmst
concretions
bioclastic lmst
tabular flint
bioclastic lmst
double tabular flint
K
J
310
305
300
295
290
285
concretions
semitabular flint
Spondylus
Plicatula
prominent bed
Spondylus frequent
T
SB5
N L J

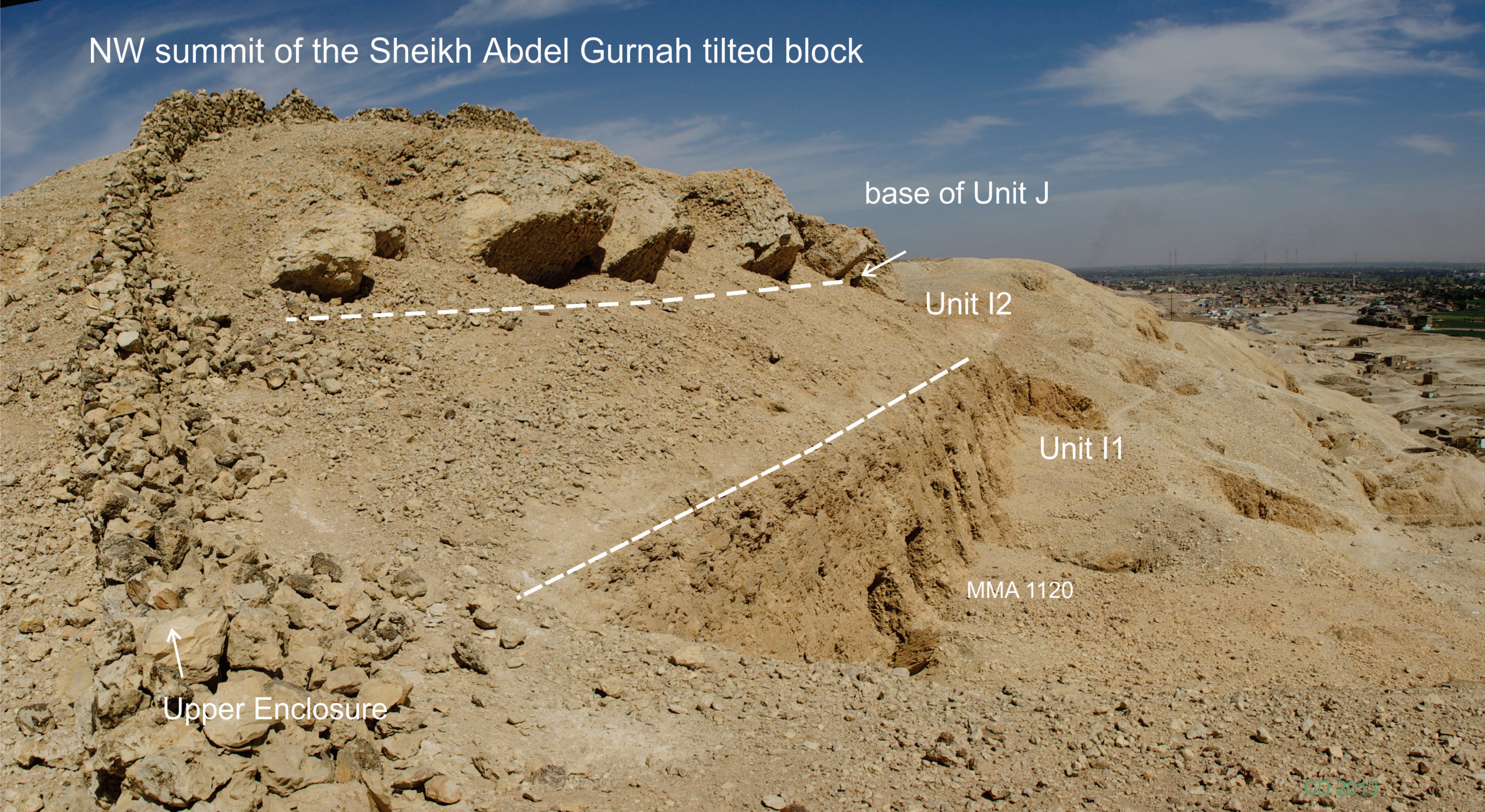


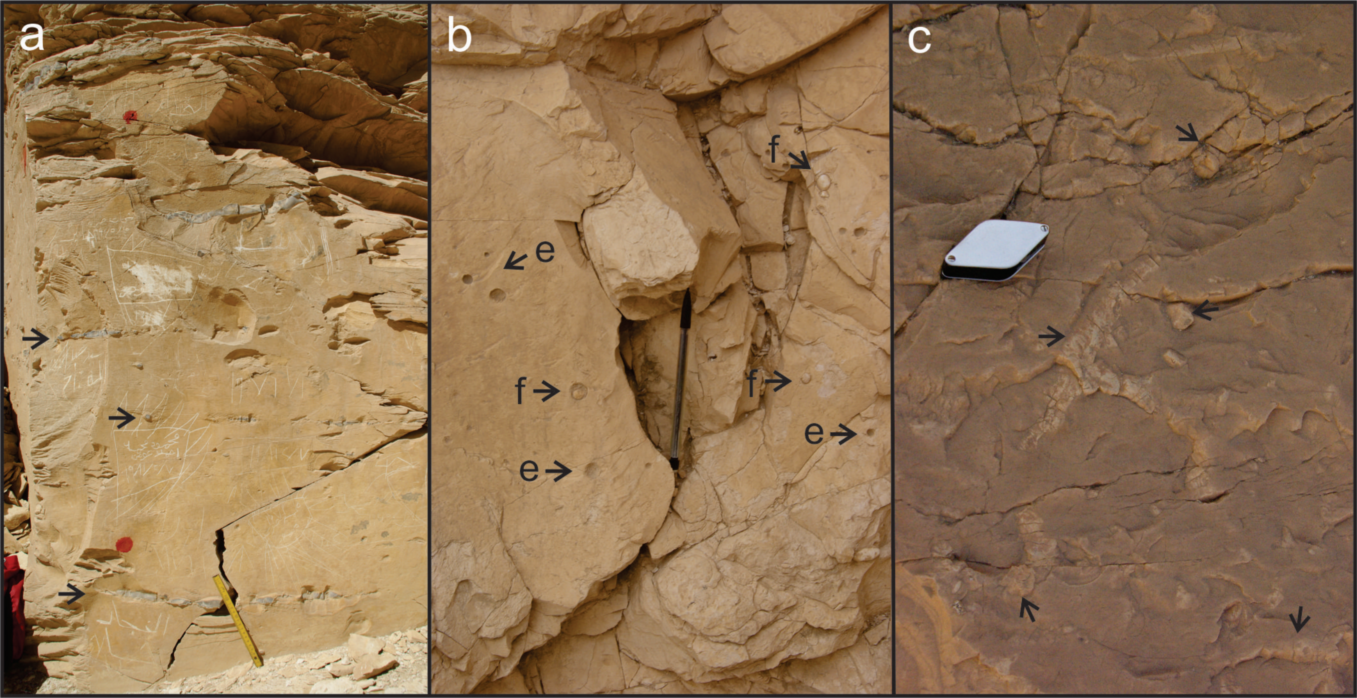
340
335
333.5
331.3
330
326
325
320
315
313.3
M
L
K
T
Turkostrea
coquina
Turkostrea
coquina
laminated lmst. beds
laminated
lmst. beds
SB6
L
L
N
thin platy
limestone
beds
coquina
bioclastic limestone
nodular limestone
concretionary lmst.
indurated limestone
limestone
argillaceous lmst.
marl
calcareous claystone
claystone
phosphate
burrowed surface
siliceous limestone
siliceous concretions
burrow-filled concretions
calcareous concretions
flint
tabular flint
oysters (T: Turkostrea)
Anodontia (Lucina)
turritellids
other gastropods
Operculina/
Nummulites

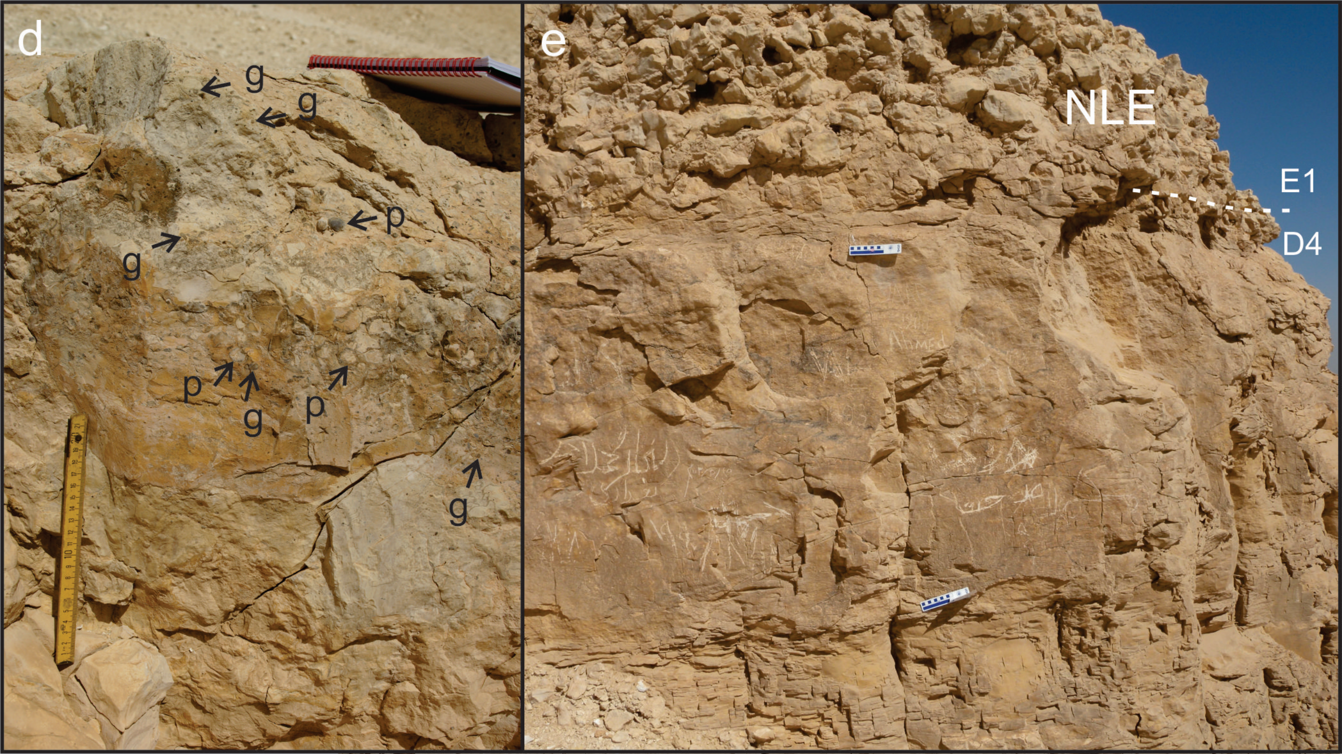

S
N
fault 3
fault 2
fault 1
C1
limestone C2
pink marl C3
red marl
C1
29

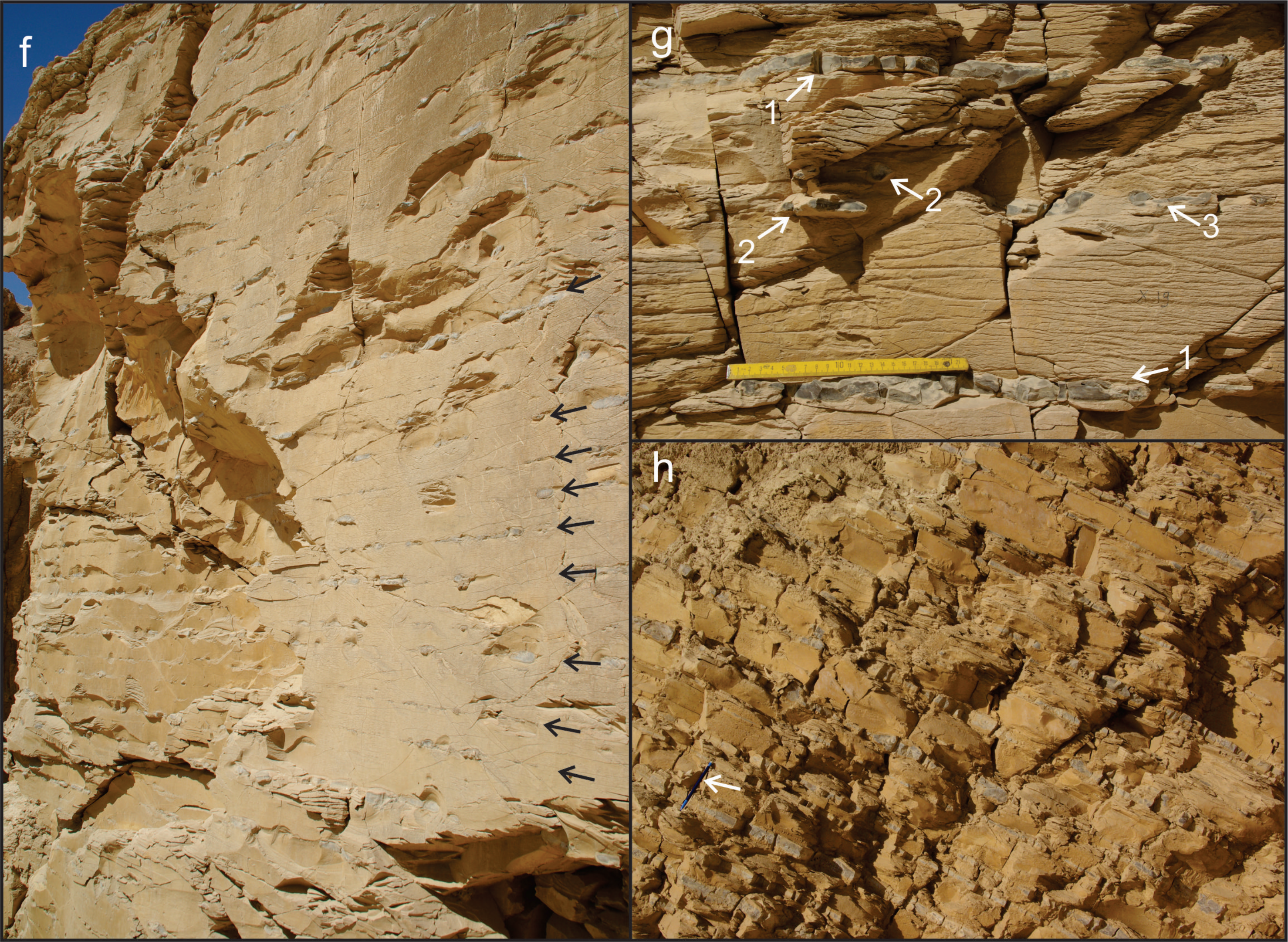

NE
SW
nodular limestone NLG
marl F4
limestone F5
marl F2
limestone F1
limestone F3
terrace of tomb TT 79
CD 2012

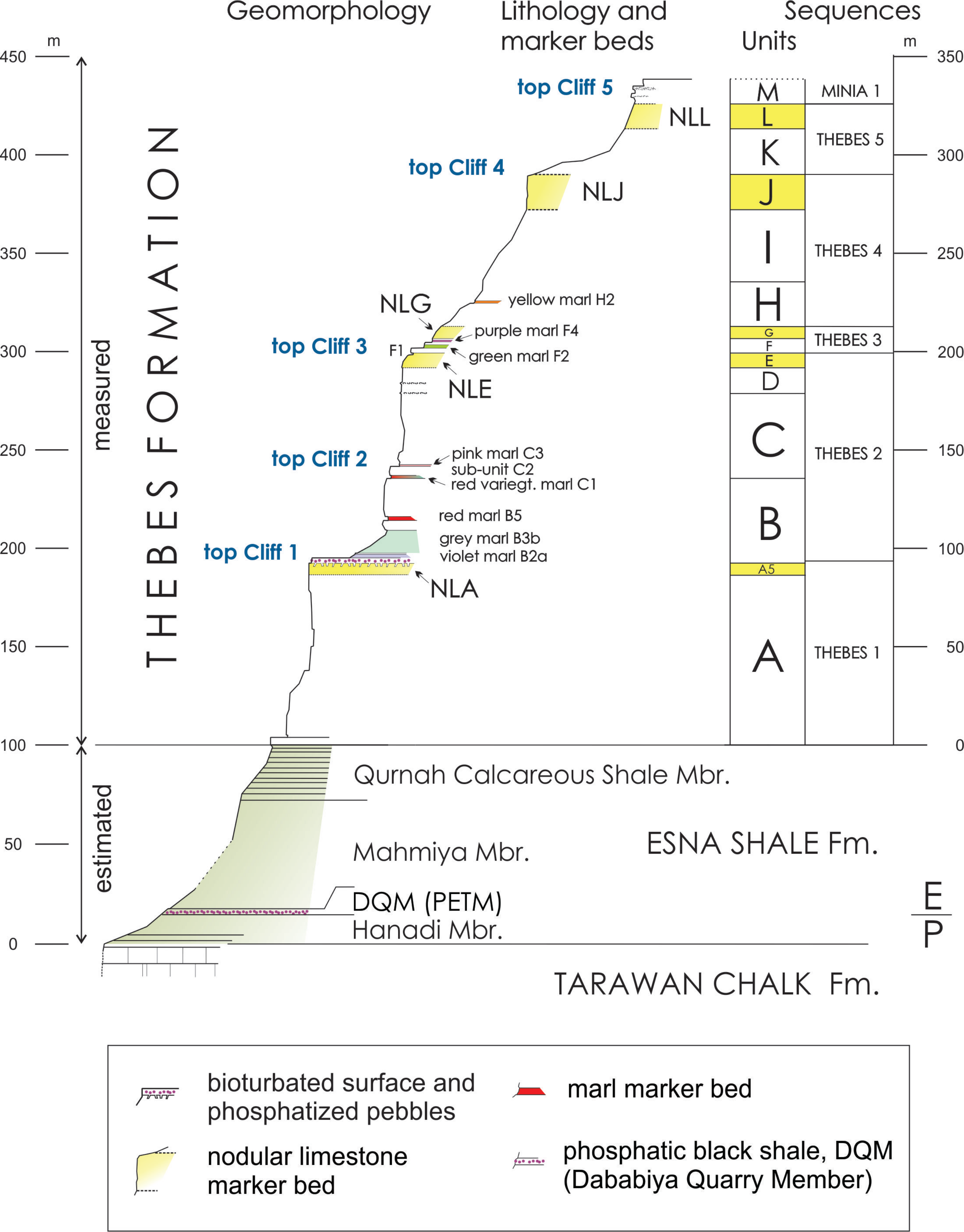

Upper Enclosure
Subunit H1
Subunit H3
yellow marl H2
CD 2014


NW summit of the Sheikh Abdel Gurnah tilted block
base of Unit J
Unit I2
Unit I1
MMA 1120
Upper Enclosure
CD 2013

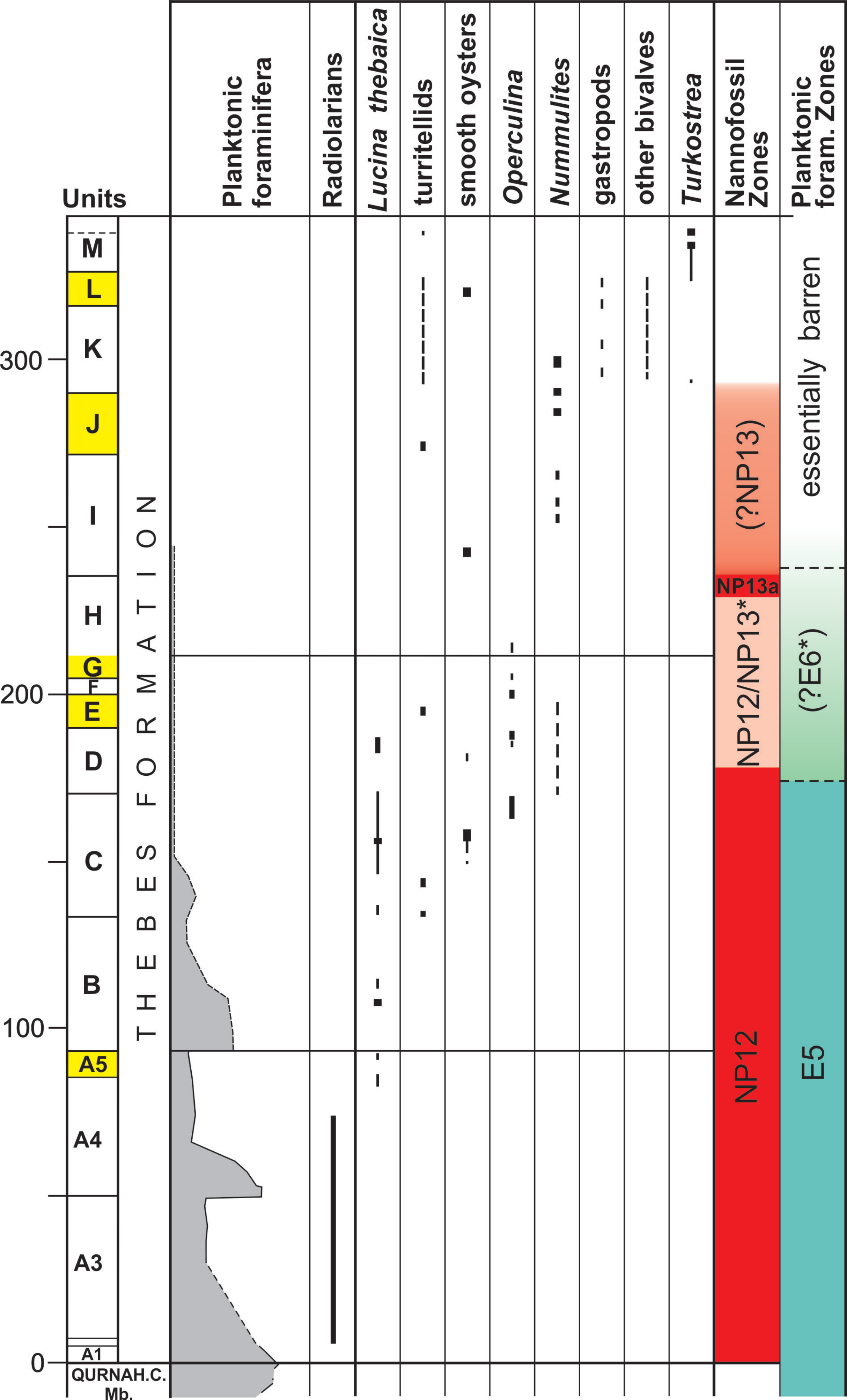

a
b
e
f
f
f
e
e
c


d
g
g
p
g
p
g
p
g
e
NLE
E1
D4

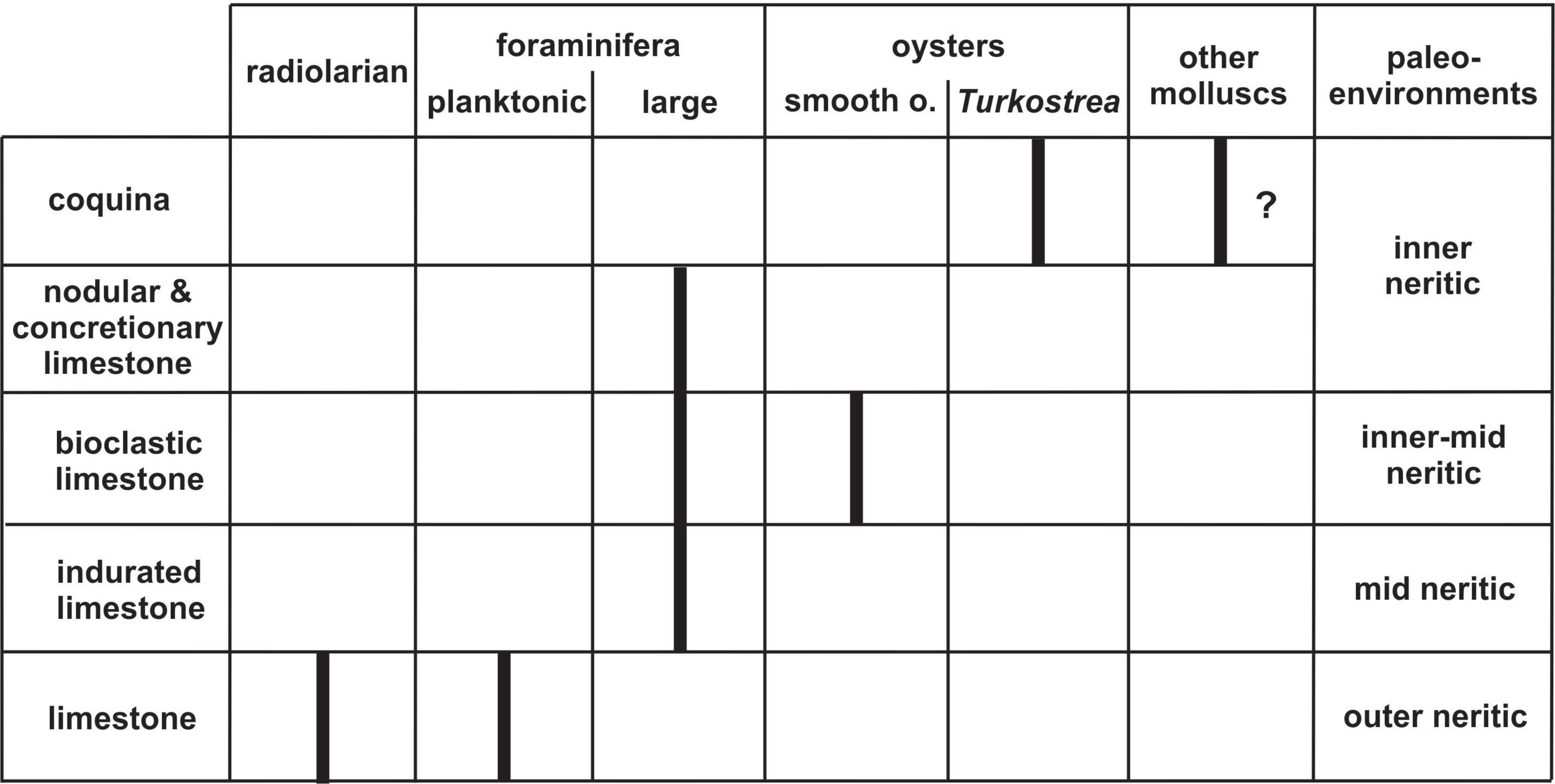

f
g
1
2
2
3
1
h



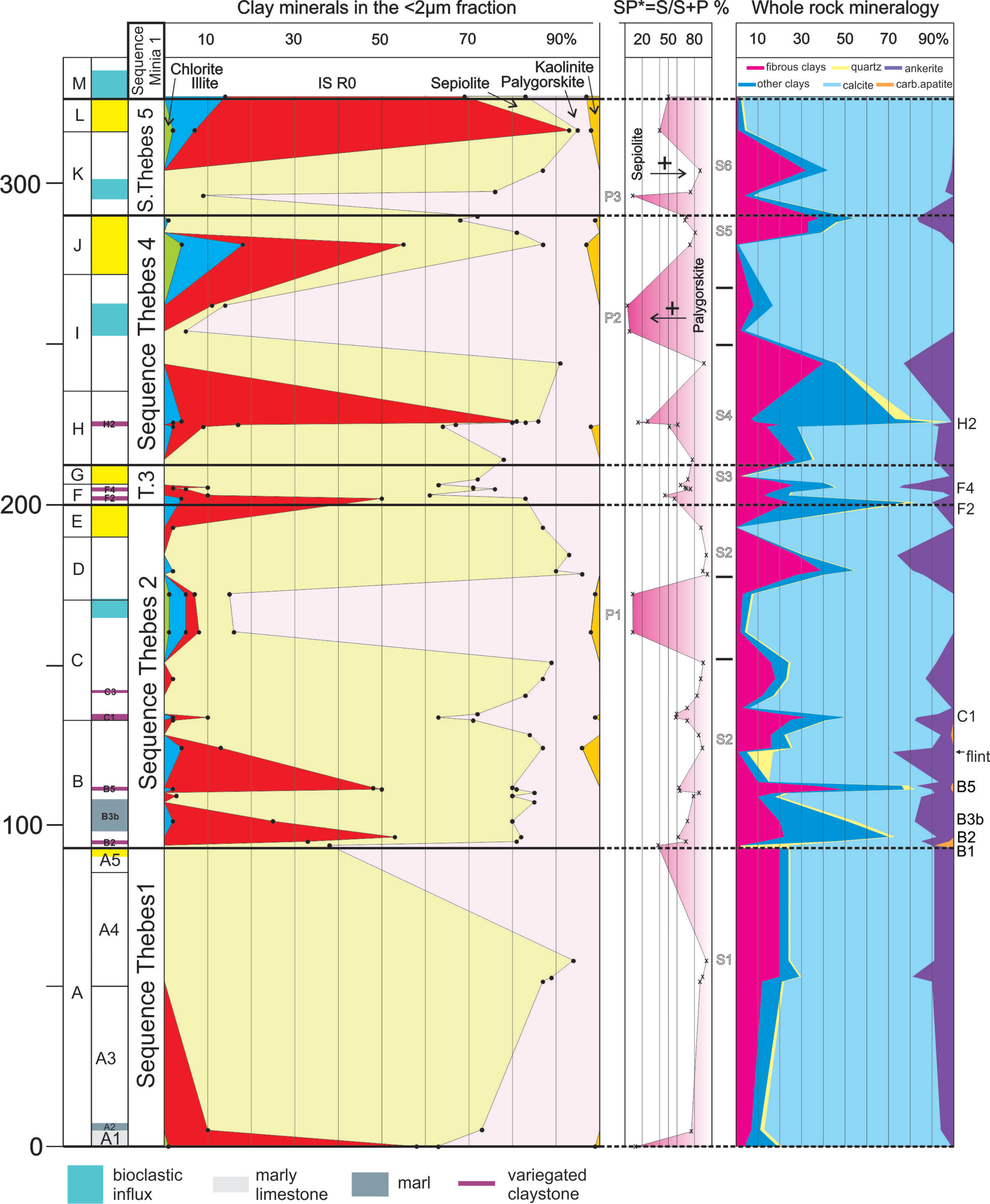
Geomorphology
Lithology and marker beds
Sequences
Units
m
450
400
350
300
250
200
150
100
50
0
m
350
300
250
200
150
100
50
0
THEBES FORMATION
measured
estimated
top Cliff 5
top Cliff 4
top Cliff 3
top Cliff 2
top Cliff 1
NLL
NLJ
NLG
NLE
NLA
F1
yellow marl H2
purple marl F4
green marl F2
pink marl C3
sub-unit C2
red variegt. marl C1
red marl B5
grey marl B3b
violet marl B2a
M
L
K
J
I
H
G
F
E
D
C
B
A5
A
MINIA 1
THEBES 5
THEBES 4
THEBES 3
THEBES 2
THEBES 1
Qurnah Calcareous Shale Mbr.
Mahmiya Mbr.
DQM (PETM)
Hanadi Mbr.
ESNA SHALE Fm.
E
P
TARAWAN CHALK Fm.
bioturbated surface and phosphatized pebbles
nodular limestone marker bed
marl marker bed
phosphatic black shale, DQM (Dababiya Quarry Member)



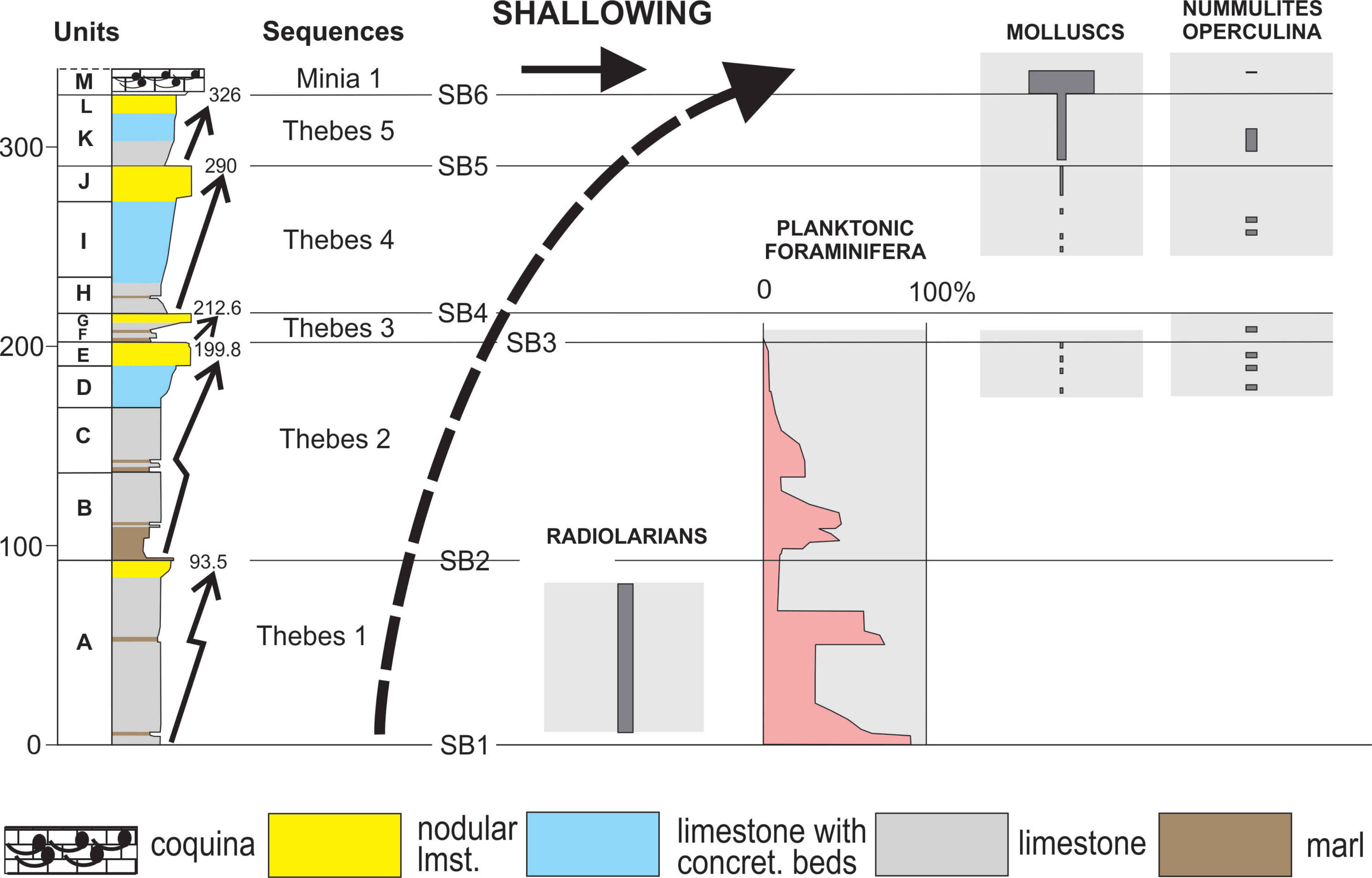
Units
Planktonic foraminifera
Radiolarians
Lucina thebaica
turritellids
smooth oysters
Operculina
Nummulites
gastropods
other bivalves
Turkostrea
Nannofossil Zones
Planktonic foram. Zones
M
L
K
J
I
H
G
F
E
D
C
B
A5
A4
A3
A1
QURNAH.C. Mb.
300
200
100
0
THEBES FORMATION
(?NP13)
NP13a
NP12/NP13*
NP12
essentially barren
(?E6*)
E5



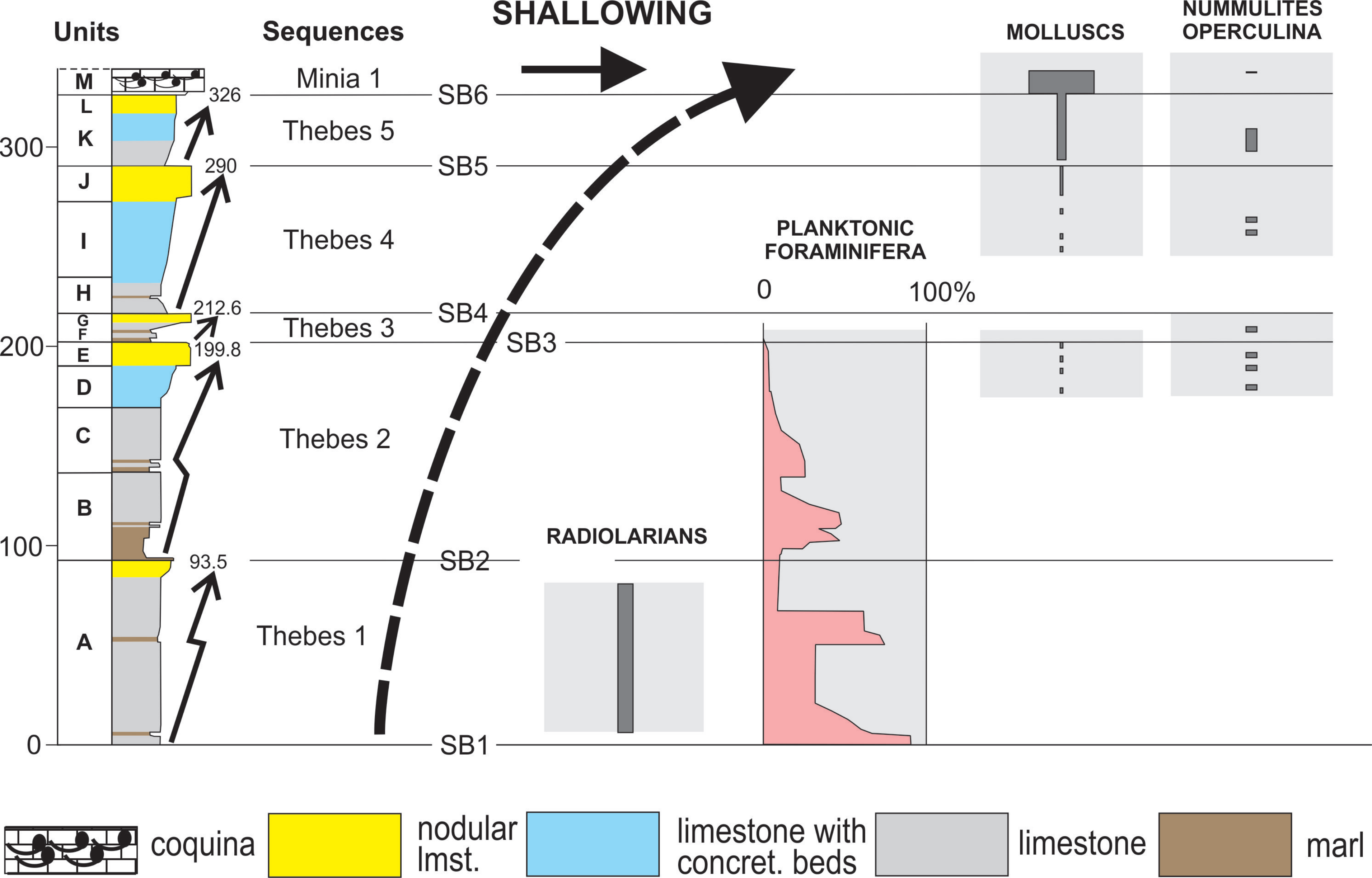
radiolarian
foraminifera
planktonic
large
oysters
smooth o.
Turkostrea
other molluscs
paleo-environments
coquina
?
nodular & concretionary limestone
bioclastic limestone
indurated limestone
limestone
inner neritic
inner-mid neritic
mid neritic
outer neritic



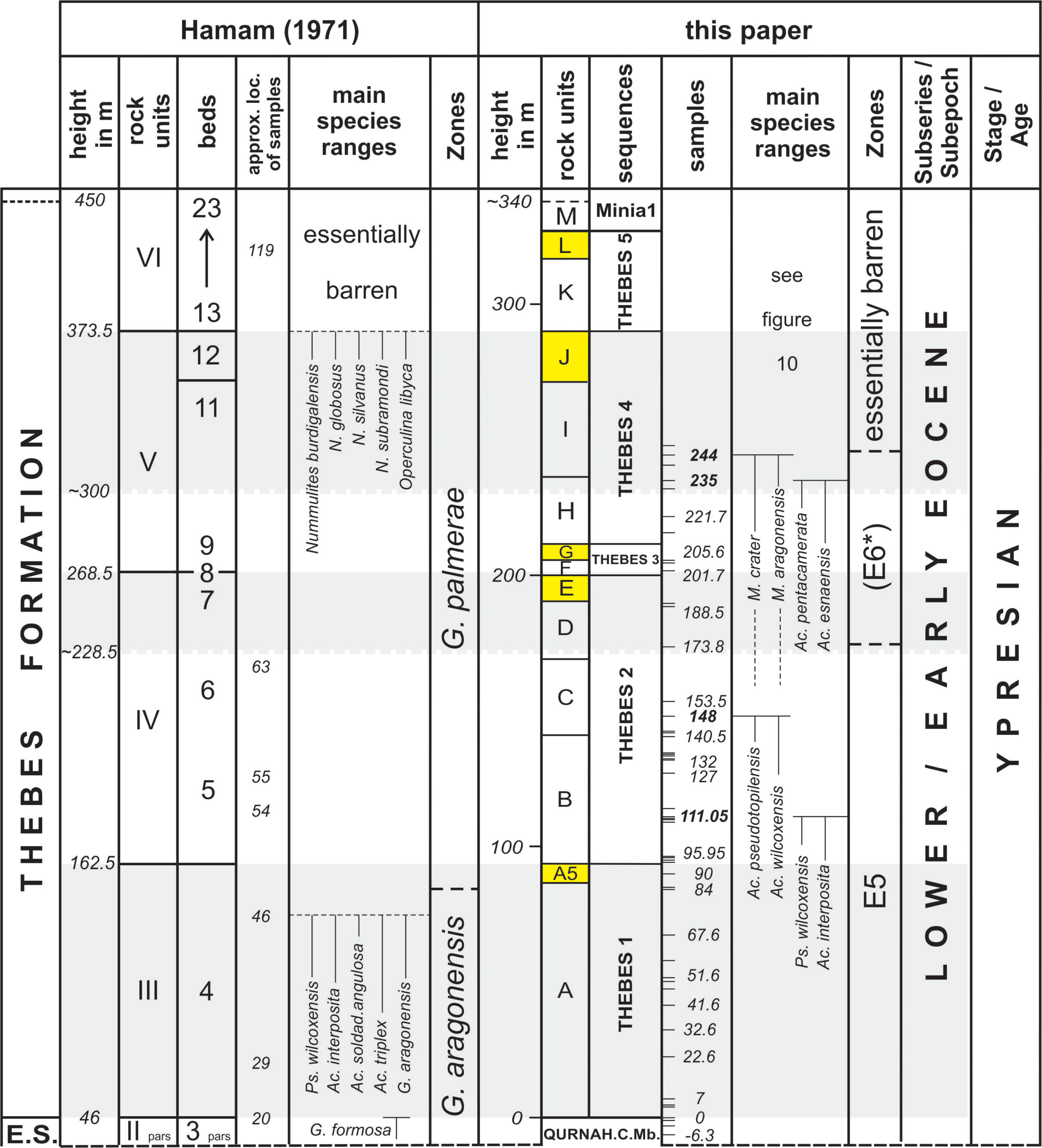
Clay minerals in the <2µm fraction
SP*=S/S+P %
Whole rock mineralogy
Sequence Minia 1
Chlorite
Illite
IS R0
Sepiolite
Palygorskite
Kaolinite
fibrous clays
quartz
ankerite
other clays
calcite
carb.apatite
S.Thebes 5
Sequence Thebes 4
T.3
Sequence Thebes 2
Sequence Thebes1
Sepiolite
Palygorskite
P1
P2
P3
S1
S2
S3
S4
S5
S6
H2
F4
F2
C1
flint
B5
B3b
B2
B1
bioclastic influx
marly limestone
marl
variegated claystone

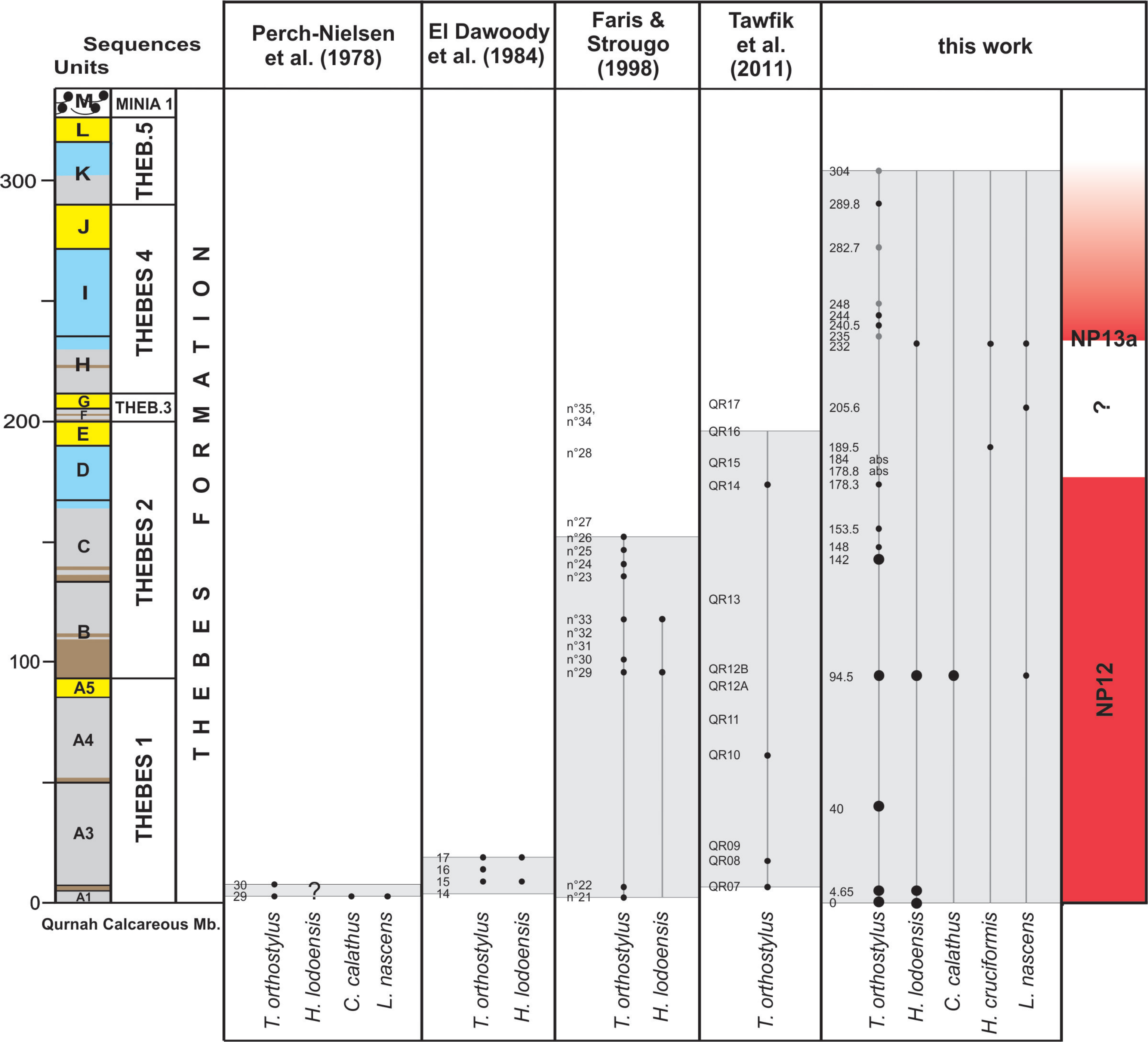


Units
Sequences
SHALLOWING
MOLLUSCS
NUMMULITES
OPERCULINA
M
L
K
J
I
H
G
F
E
D
C
B
A
300
200
100
0
326
290
212.6
199.8
93.5
Minia 1
Thebes 5
Thebes 4
Thebes 3
Thebes 2
Thebes 1
SB6
SB5
SB4
SB3
SB2
SB1
PLANKTONIC
FORAMINIFERA
0
100%
RADIOLARIANS
coquina
nodular
lmst.
limestone with
concret. beds
limestone
marl

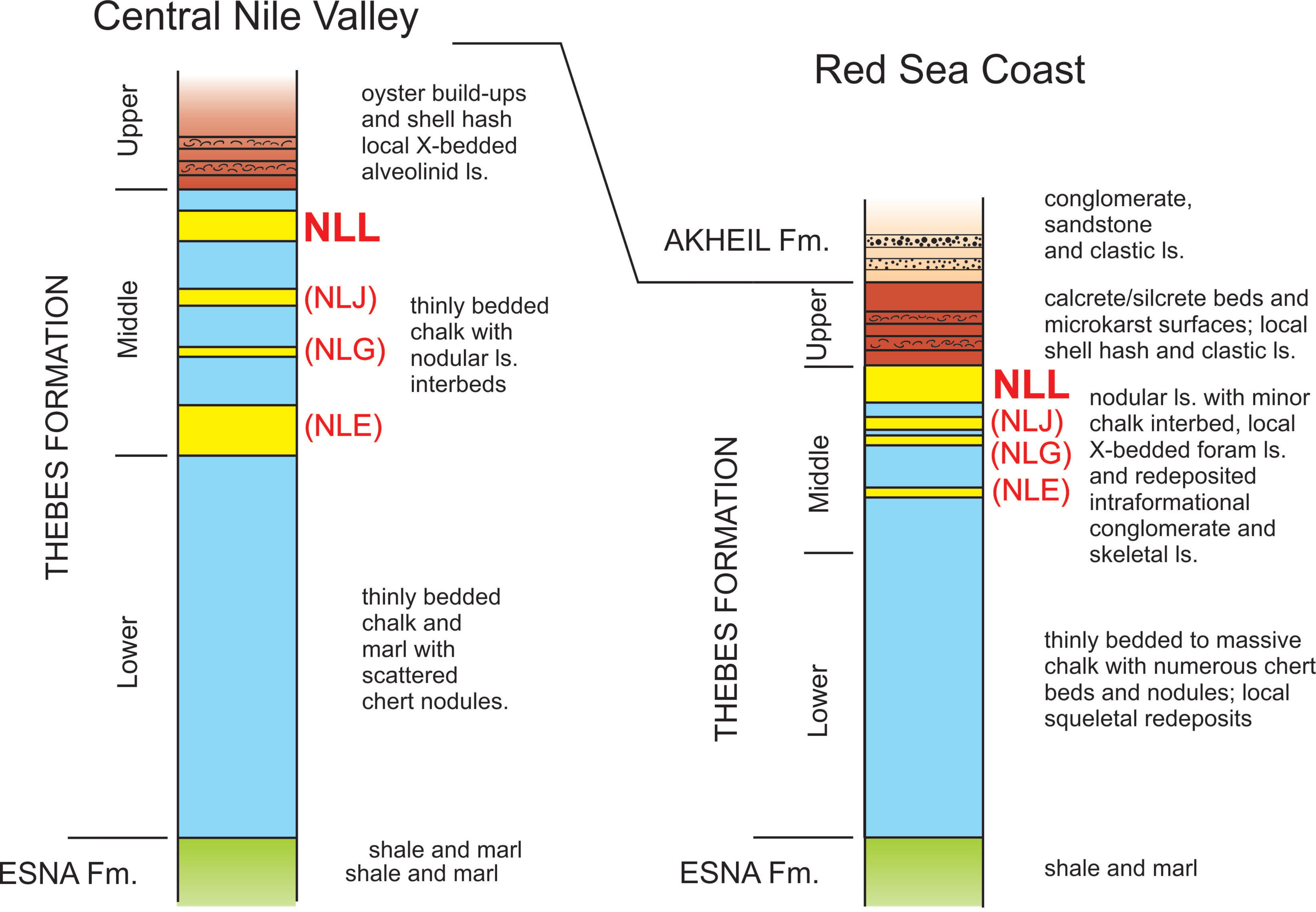


Units
Sequences
SHALLOWING
MOLLUSCS
NUMMULITES
OPERCULINA
M
L
K
J
I
H
G
F
E
D
C
B
A
300
200
100
0
326
290
212.6
199.8
93.5
Minia 1
Thebes 5
Thebes 4
Thebes 3
Thebes 2
Thebes 1
SB6
SB5
SB4
SB3
SB2
SB1
PLANKTONIC
FORAMINIFERA
0
100%
RADIOLARIANS
coquina
nodular
lmst.
limestone with
concret. beds
limestone
marl

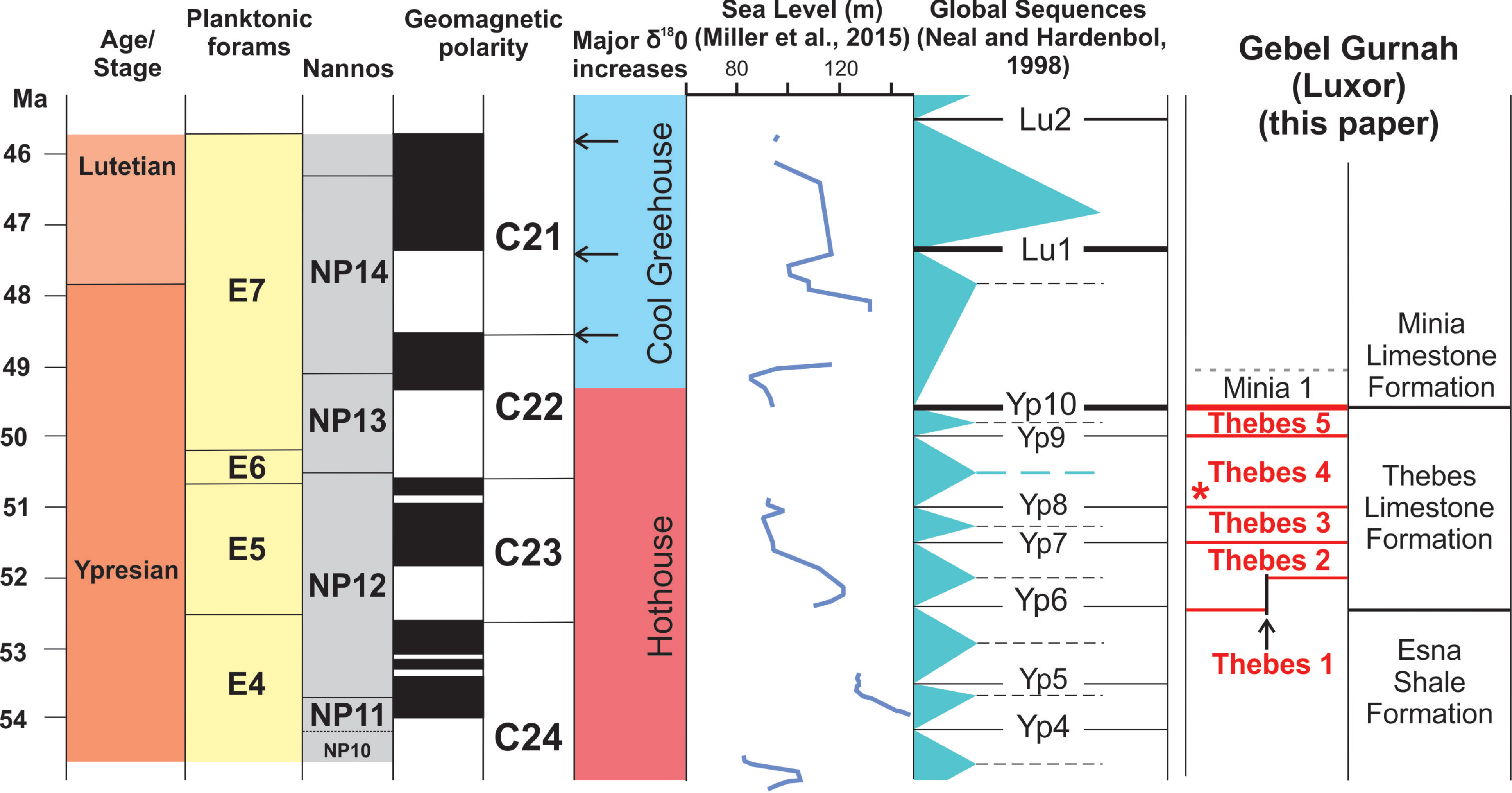

Hamam (1971)
this paper
height in m
rock units
beds
approx. loc. of samples
main species ranges
Zones
height in m
rock units
sequences
samples
main species ranges
Zones
Subseries / Subepoch
Stage / Age
THEBES FORMATION
E.S.
450
373.5
~300
268.5
~228.5
162.5
46
VI
V
IV
III
II pars
23
13
12
11
9
8
7
6
5
4
3 pars
119
63
55
54
46
29
20
essentially barren
Nummulites burdigalensis
N. globosus
N. silvanus
N. subramondi
Operculina libyca
Ps. wilcoxensis
Ac. interposita
Ac. soldad.angulosa
Ac. triplex
G. aragonensis
G. formosa
G. palmerae
G. aragonensis
~340
300
200
100
0
M
L
K
J
I
H
G
F
E
D
C
B
A5
A
QURNAH.C.Mb.
Minia1
THEBES 5
THEBES 4
THEBES 3
THEBES 2
THEBES 1
244
235
221.7
205.6
201.7
188.5
173.8
153.5
148
140.5
132
127
111.05
95.95
90
84
67.6
51.6
41.6
32.6
22.6
7
0
-6.3
see figure 10
M. crater
M. aragonensis
Ac. pentacamerata
Ac. esnaensis
Ac. pseudotopilensis
Ac. wilcoxensis
Ps. wilcoxensis
Ac. interposita
essentially barren
(E6*)
E5
LOWER / EARLY EOCENE
YPRESIAN

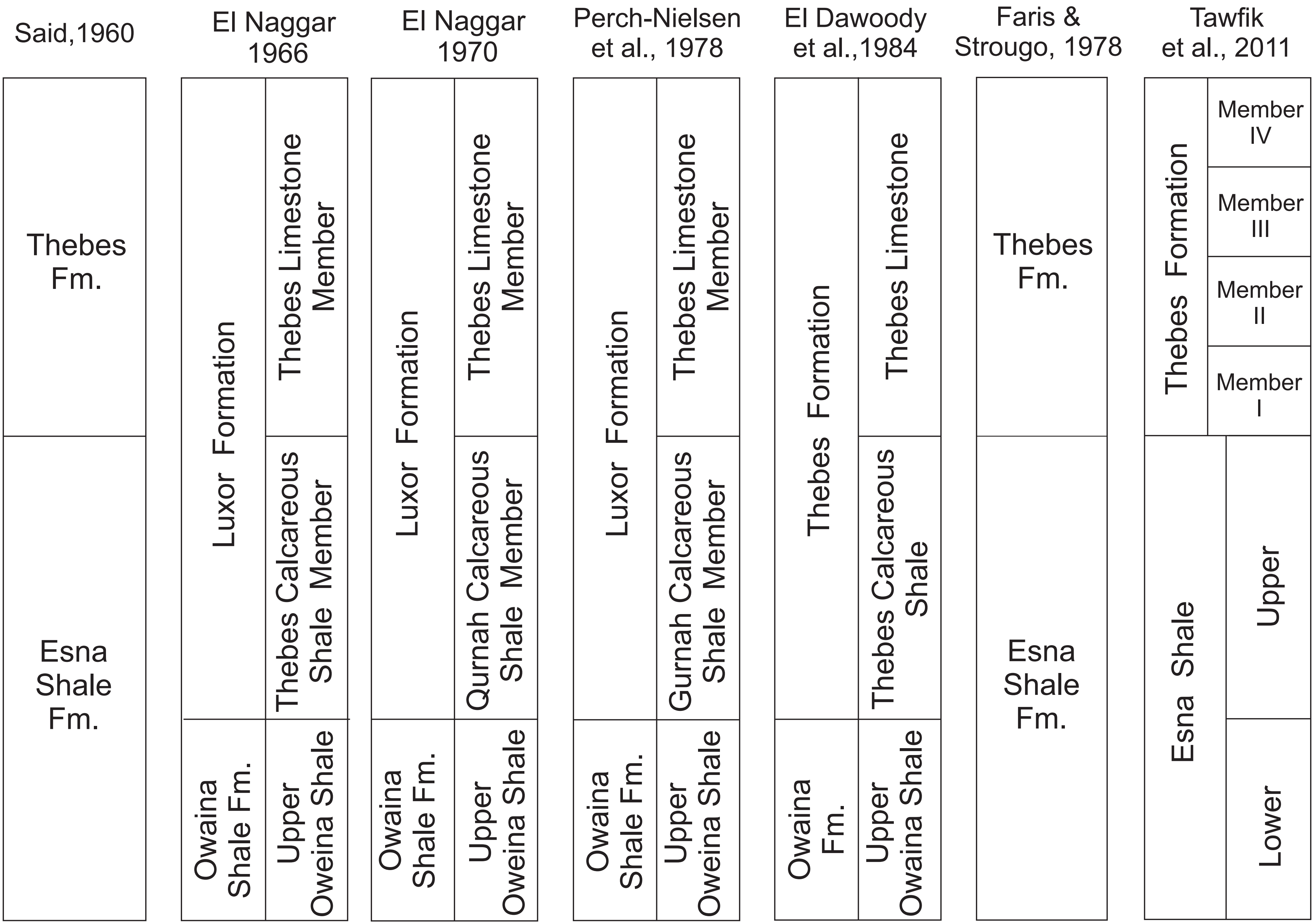


Sequences
Units
Perch-Nielsen et al. (1978)
El Dawoody et al. (1984)
Faris & Strougo (1998)
Tawfik et al. (2011)
this work
MINIA 1
THEB.5
THEBES 4
THEB.3
THEBES 2
THEBES 1
THEBES FORMATION
Qurnah Calcareous Mb.
M
L
K
J
I
H
G
F
E
D
C
B
A5
A4
A3
A1
300
200
100
0
30
29
17
16
15
14
n°35,
n°34
n°28
n°27
n°26
n°25
n°24
n°23
n°33
n°32
n°31
n°30
n°29
n°22
n°21
QR17
QR16
QR15
QR14
QR13
QR12B
QR12A
QR11
QR10
QR09
QR08
QR07
304
289.8
282.7
248
244
240.5
235
232
205.6
189.5
184
178.8
178.3
153.5
148
142
94.5
40
4.65
0
abs
abs
NP13a
?
NP12
T. orthostylus
H. lodoensis
C. calathus
L. nascens
H. cruciformis



Central Nile Valley
Red Sea Coast
Upper
Middle
Lower
THEBES FORMATION
oyster build-ups and shell hash local X-bedded alveolinid ls.
NLL
(NLJ)
(NLG)
(NLE)
thinly bedded chalk with nodular ls. interbeds
thinly bedded chalk and marl with scattered chert nodules.
ESNA Fm.
shale and marl
shale and marl
AKHEIL Fm.
conglomerate, sandstone and clastic ls.
calcrete/silcrete beds and microkarst surfaces; local shell hash and clastic ls.
Upper
NLL
(NLJ)
(NLG)
(NLE)
nodular ls. with minor chalk interbed, local X-bedded foram ls. and redeposited intraformational conglomerate and skeletal ls.
Middle
THEBES FORMATION
Lower
thinly bedded to massive chalk with numerous chert beds and nodules; local squeletal redeposits
ESNA Fm.
shale and marl


Ma
Age/ Stage
Planktonic forams
Nannos
Geomagnetic polarity
Major δ18O increases
Sea Level (m) (Miller et al., 2015)
80
120
Global Sequences (Neal and Hardenbol, 1998)
Gebel Gurnah (Luxor) (this paper)
46
47
48
49
50
51
52
53
54
Lutetian
Ypresian
E7
E6
E5
E4
NP14
NP13
NP12
NP11
NP10
C21
C22
C23
C24
Cool Greehouse
Hothouse
Lu2
Lu1
Yp10
Yp9
Yp8
Yp7
Yp6
Yp5
Yp4
Minia 1
Thebes 5
Thebes 4
*
Thebes 3
Thebes 2
Thebes 1
Minia Limestone Formation
Thebes Limestone Formation
Esna Shale Formation


Said,1960
El Naggar 1966
El Naggar 1970
Perch-Nielsen et al., 1978
El Dawoody et al.,1984
Faris & Strougo, 1978
Tawfik et al., 2011
Thebes Fm.
Esna Shale Fm.
Luxor Formation
Thebes Limestone Member
Thebes Calcareous Shale Member
Owaina Shale Fm.
Upper Oweina Shale
Luxor Formation
Thebes Limestone Member
Qurnah Calcareous Shale Member
Owaina Shale Fm.
Upper Oweina Shale
Luxor Formation
Thebes Limestone Member
Gurnah Calcareous Shale Member
Owaina Shale Fm.
Upper Oweina Shale
Thebes Formation
Thebes Limestone
Thebes Calcareous Shale
Owaina Fm.
Upper Owaina Shale
Thebes Fm.
Esna Shale Fm.
Thebes Formation
Member IV
Member III
Member II
Member I
Esna Shale
Upper
Lower

samples	units	chlorite	illite	ISR0	sepiolite	palygorskite	kaolinite	S*=S:S+P 100	fibr. min.	other clays	quartz	calcite	ankerite	carb. apatite
TH 327.2		0	14	55	14	14	3	50	1	1	1	97	0	0
TH 316.5		2	5	86	2	3	2	40	1	3	1	95	0	0
TH 304	M	0	0	0	87	13	0	87	32	10	0	57	1	0
TH 297.25		0	0	0	76	24	0	76	8	3	0	85	4	0
TH 296.9		0	0	0	9	91	0	9	4	4	1	90	0	0
TH 289.8	to	0	0	0	72	28	0	72	38	16	1	28	17	0
TH 288.7		1	0	0	67	31	1	68.3	33	12	1	38	16	0
TH 284.7		0	0	0	81	19	0	81	32	6	1	55	6	0
TH 281		4	14	37	32	10	3	76.2	0	1	0	99	0	0
TH 262	H3	0	0	11	2	87	0	2.2	8	8	0	84	0	0
TH 254		0	0	0	5	95	0	5	2	2	0	96	0	0
TH 244		0	0	0	91	9	0	91	40	6	1	30	23	0
TH225.6		0	4	77	5	14	0	26.3	7	66	8	17	2	0
TH 225.3	H2	0	2	78	3	17	0	15	9	81	9	0	1	0
TH 225		0	0	17	50	33	0	60.2	20	32	1	37	10	0
TH 224.7		0	2	7	45	44	2	50.5	14	14	0	65	7	0
TH 214.1	H1	0	0	0	78	22	0	78	27	8	1	55	9	0
TH 208	to	0	0	0	72	28	0	72	2	0	2	94	2	0
TH 206.2	F5	0	0	0	63	37	0	63	16	9	0	63	12	0
TH 205.6		0	0	10	61	29	0	67.7	21	19	1	43	16	0
TH 205.2	F4	0	0	2	69	29	0	70.4	26	17	1	34	22	0
TH 205		0	0	5	71	24	0	74.7	23	21	1	30	25	0
TH 204.7	F3	0	5	9	40	46	0	46.5	16	9	1	69	5	0
TH 202.3		0	0	10	51	39	0	56.6	14	10	1	73	2	0
TH 202	F2	0	4	46	33	17	0	68	24	54	5	7	10	0
TH 192.5		0	0	3	84	13	0	86.6	0	0	0	100	0	0
TH 184	F1	0	0	0	93	7	0	93	28	3	1	42	26	0
TH 179		0	2	0	88	10	0	89.7	39	15	1	26	19	0
TH 178		0	0	0	96	4	0	96	28	12	1	45	14	0
TH 171.8	to	2	3	2	8	84	1	8.7	3	4	1	92	0	0
TH 160		1	4	3	8	82	2	8	2	2	1	95	0	0
TH 150.5		0	0	0	89	11	0	89	16	8	1	67	8	0
TH 145.5	C2	0	0	2	85	13	0	86.7	18	5	1	63	13	0
TH 140.5		0	0	0	83	17	0	83	12	4	1	77	6	0
TH 134		0	0	0	72	28	0	72	3	3	0	93	1	0
TH 133.6			NO		DATA				15	14	1	63	7	0
TH 133.1	C1	2	0	8	53	36	1	59.5		NO			DATA	
TH 132.9			NO		DATA				32	18	1	32	17	0
TH 132.5		0	0	2	69	29	0	70.4	25	16	1	40	18	0
TH 128		0	0	0	84	16	0	84	16	6	1	71	5	1
TH 124	B6	0	4	9	74	9	4	89.1	16	9	1	64	10	0
TH 122.9			not		enough		clay		1	4	12	56	27	0
TH 111.4		0	0	48	32	20	0	61.5	36	40	3	4	16	1
TH 111		0	2	52	28	18	0	60.8		NO			DATA	
TH 110.8	B5	0	2	48	31	19	0	62	49	28	5	8	9	1
TH 110.5		0	2	52	28	18	0	60.8		NO			DATA	
TH 110.25		0	0	0	83	17	0	83	10	5	0	78	7	0
TH 110	B4	0	0	0	85	15	0	85	17	5	2	67	9	0
TH 109		0	0	3	77	20	0	79.4	10	8	2	65	14	0
TH 101	B3	0	2	24	54	20	0	72.9	20	31	4	27	18	0
TH 95.8	B2	0	0	53	29	18	0	61.7	22	48	3	19	8	0
TH 94		0	0	33	48	19	0	71.6	13	33	3	35	13	2
TH 93.5	B1	0	0	0	38	62	0	38	2	0	25	63	1	9
TH 57.8		0	0	0	94	6	0	94	20	4	1	66	9	0
TH 51.6		0	0	0	89	11	0	89	20	9	1	51	19	0
TH 50.35	A	0	0	0	87	13	0	87	12	9	1	68	0	0
TH 4.65		0	0	10	73	17	T	81	7	4	1	64	5	1
TH 0.00		1	0	57	5	36	1	12.2	4	15	2	78	1	0

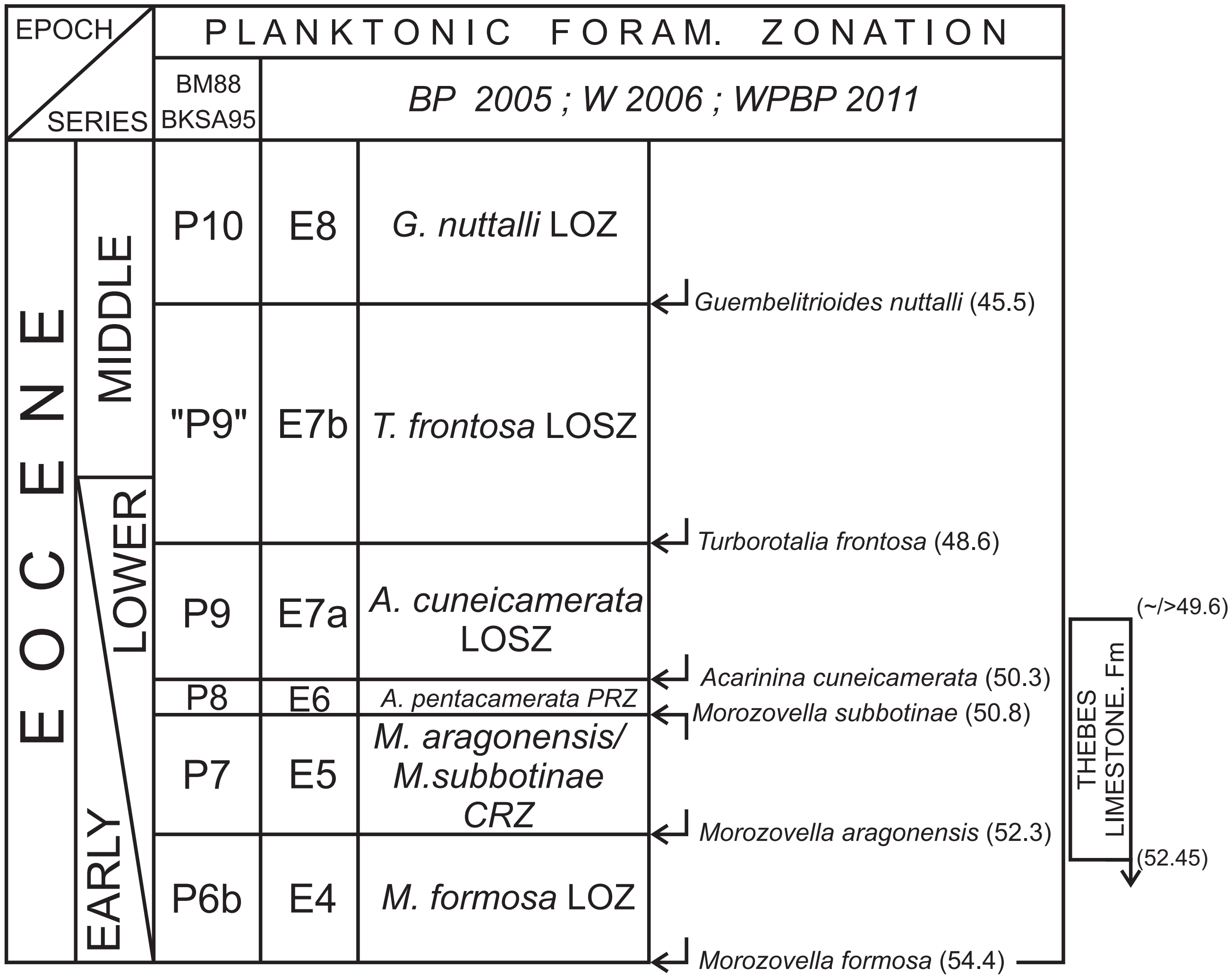

EPOCH
SERIES
PLANKTONIC FORAM. ZONATION
BM88
BKSA95
BP 2005 ; W 2006 ; WPBP 2011
EOCENE
MIDDLE
LOWER
EARLY
P10
E8
G. nuttalli LOZ
Guembelitrioides nuttalli (45.5)
"P9"
E7b
T. frontosa LOSZ
Turborotalia frontosa (48.6)
P9
E7a
A. cuneicamerata LOSZ
Acarinina cuneicamerata (50.3)
P8
E6
A. pentacamerata PRZ
Morozovella subbotinae (50.8)
P7
E5
M. aragonensis/ M.subbotinae CRZ
Morozovella aragonensis (52.3)
P6b
E4
M. formosa LOZ
Morozovella formosa (54.4)
(~/>49.6)
THEBES LIMESTONE. Fm
(52.45)

Illustration	Name	Description	Reference
Fig. 14: F	"*Planorotalites pseudomenardii*"	4 chambered, form with inflated chambers, and rounded (unkeeled) periphery	Olsson et al., 1999, Plate 38
Fig. 14: G	"*Globorotalia compressa*"	coarsely perforate, 6-7 inflated chambers, single view (?planispiral or trochoid)	Olsson et al., 1999, Pl. 35, Figs.1-7
Fig. 14: H	*"Morozovella angulata"*	quadrate, 4-rounded, inflated chambers, non-anguloconical test; single view	Olsson et al., 1999, Plate 48
Fig. 14: I, J, K	*"Globigerina triloculinoides"* (3 different specimens)	four (presumably cancellate), rounded, inflated chambers; probably subbotinid (?*Subbotina patagonica*)	Olsson et al., 1999, Plate 27
Fig. 14: L	"*Planorotalites pusilla pusilla*":	5-chambered, cancellate, single (umbilical) view	Olsson et al., 1999, Pl. 16, Figs. 7-9; Plate 57
Fig. 14: M, N	"*Morozovella uncinata*"	4-chambered, cancellate (two specimens; unrelated taxa); lacking angulo-conical tests of *Praemurica uncinata*	Olsson et al., 1999, Plate 62

Lithostratigraphy: Formations	Units	height (metres) (label)	*Ps. wilcoxensis*	*S. patagonica*	*Morozovella* sp. indet.	Pl. pseudoscitula	*Ac. alticonica*	*Ac. boudreauxi*	*Ac. coalingensisis*	*Ac. esnaensis*	*Ac. interposita*	*Ac. pentacamerata*	*Ac. primitiva*	*Ac. pseudotopilensis*	*Ac. quetra*	*Ac. soldadoensis*	*Ac. sp. indet.*	*Ac. wilcoxensis*	*Mor. aequa*	*Mor. aragonensis*	*Mor. gracilis*	*Mor. cf. lensiformis*	*Mor. subbotinae*	*Ig. broedermanni*	*Ac. esnehensis*	*Ac. angulosa*	*Mor. crater*	*Globanomalina* sp.	*Parasub. inaequispira*	Zone (Wade et al., 2011)	Subseries / Subepoch	Stage / Age
Thebes Formation		TH																												?E5	LOWER / EARLY EOCENE	YPRESIAN
	I	c.248.0		?fr																												
		244																		x												
		240,5																														
	H3	235		fr	x					x		x					x															
		232								x												cf.										
	H2	221,7		x																												
	H1	215,7		cf																												
	F4	205,6		x																												
	F3	204,7																														
	F2	201,7																														
	D4	189,5																														
		c. 188.5																														
	D1	173,8																														
	C4	153,5		x																										E5		
		148	x	x										x			cf.															
		142		dom																												
	C3	141,85	?	x																												
	C2	140,5		x			cf.				x																					
		134,5	x							x		x		x	x																	
	C1	134,15	fr	x	cf																											
		133,8																														
		132,6	c		x											x																
	B7	132	cf						cf.			x	x																			
	B6	127																														
		114	fr								x		x					x		cf.												
	B5	111,05	x					cf.			x	x			x	x		x											cf.			
	B4	110,45	c									x	cf.					x											x			
		110.05B	vc	vc																												
		109	x														x															
	B3A	95,95	vc																													
	B2B	95,8																														
	B2A	94,5			fr																											
		c.94.1		oc	x				c		x	x					x			x												
	A5	90																														
	A4	85																														
		84	x	x																												
		67,6	fr	fr	fr												x	x														
		57,8	c	c	fr						x																					
		51,6	fr																													
	A3	50,35	fr																													
		47,6																														
		41,6	fr																													
		32,6	c								x	x						x										x				
		22,6	x	cf																												
		7																														
	A1	4,65	c	x	fr	c						x																				
		4																														
		0	c	x	x	f	x	x	x	x		x		x		x	x	x			x		x									
ESNA	ES (GM)	-1		fr							x		x	fr		x			x					x								
		-3	x	fr		x				x	x			x		x				x	x			x			x					
		-6,3	x	fr							x	x		x		fr		x					x	x	x	x	x					

Site	Unit	Height (metres) (label)	split for Marie	abundance	preservation	B. bigelowii	Br. serraculoides	Campy. dela	Chia. consuetus	Chia. solitus	Chip. calcthus	C.crassus	C. pelagicus s.l.	Helio-Discoaster barbadisnsis	H. binodosus	H. cruciformis	H. falcatus	H. gemmifer	H. kuepperi	H. lodoensis	H. minutus	H. pacificus	H. praebifa	H. robustus	overgrown discoasters	E. macellus	Eric. formosa	G. gammation	Loph. nascens	Mark. inversus	Micranth. flos	M. vesper	Micranth. spp.	Pon. fimbriata	P. plana	P. wechesensis	Scyphos. sp.	Sph. radians	Su. consueta	Toweius spp.	Tri. orthostylus	Tro. simplex	Z. bijugatus	Z. herlynii	Zone (Martini, 1971)	Subseries / Subepoch	Stage / Age
ELQC	L	321.5																																													
		316.5	X	B																																											
	K	304.0	X	VR	VP																CF																					CF						
		296.9	X	B																																											
ELQC		289.8	X	VR	P																						3		X														X	1						
	G	288.7	X	VR	P	X													CF	5						7																CF						
		284.65	X	B																																											
UNL																																															
		c.262.0	X	B																																									NP12?		
		254.0	X	B																																											
	I	c.248.0	X	VR	VP																CF						14																CF						
		244.0	X	VR	P									2						CF						7						X										13						
SAG		240.5	X	F	P					X		X	X						X	1						22						X	X								X	13						
	H3	235.0	X	VR	P					X		X	X	1					X	1								X	X		1	X	X					X		X	X		X					
		232.0	X	C	M/P	X		X		X		X	X	16	1	7		X	X	11	2	1			2		X		X		X							X		X	38						
	H2	221.7	X	VR	P	X					CF	X							12	CF					7		X														X							
		215.7	X	B																																											
	H1	214.1	X	VR	VP																																										
MNL(G)																																															
	F5	205.7	X	VR	P								X																												X							
	F4	205.6	X	VR	P	X	AFF.			X		X	X	8					X						9		X		X				X							X			X				
SAG	F3	204.7	X	VR	VP					CF									1	CF																					X							
	F2	201.7	X	VR	VP																				1																						
LNL(E)																																															
ELQA																																															
	D4	189.5	X	VR	P							CF		10		CF			X					1	X		X															5						
		c. 188.5	X	R	P			X					X	1					X						X											X				X	9						
	D3	184.0	X	VR	P								X						X																					X							
	D2	178.8	X	VR	P							X		4		CF			X	6							X				X									X	CF						
	D1	173.8	X	B																																											
		153.5	X	B																																											
SAG	C4	148.0	X	VR	VP							X		X					X											X	X									X	X						
		142.0	X	VR	VP																																				X						
	C3	141.85	X	R	P																										X										X						
	C2	140.5	X	R	P														X	CF																					X						
		134.5	X	VR	VP																						X																				
	C1	133.8	X	VR	VP								X																																		
		132.6	X																																												
ELQX																																															
		132.0	X	VR	VP																																			X							
SAG	B6	127.0	X	F	VP																											X								X	X						
		122.9	X	VR	P					X										X												X		X						X	X		X				
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	B2	mid (c. 94.5)	X	C	G/M	X		X		X	X	CF	X	46	20		3	CF	26	2		4				X	X	X	X			X		C	X	X		X	X	A	236		X				
cable																																															
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SAG	A5	90.0		B																																											
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	A1	4.0		R	P									X	X							X	X																	X	X						
		2.0																																													
		0.0		C	G/M	X		X	X	X				X	C				X	1		X				X	X								X					X	210		X	X			

Appendix 1.

The earliest systematic study of the geology of Egypt (Zittel 1883) divided the Eocene into three regional 'stufe' [stages]: *Libysche stufe*, *Mokattam-stufe* and *Obereocaene stufe*, corresponding approximately to Lower, Middle and Upper Eocene. The Libysche stufe was itself divided into lower and upper units. The *Unterlibysche* [lower Libyan] *stufe* was typified by sections in the Western Desert, including Kharga Oasis, and the Nile Valley between Esna and Thebes, characterized by *Operculina libyca* and locally by fusiform alveolinids, including *Alveolina oblonga.* It corresponds approximately to the Thebes Group. The *Oberlibysche* [upper Libyan] *stufe* ('Alveolinenkalk': *Alveolina* limestone) was based on sections further north in the Nile Valley, from Assiut northwards, and was characterized by globular Alveolinids including *Alveolina frumentiformis*. The base of the overlying Mokattam-stufe was taken at the first occurrence of *Nummulites gizehensis*. Although nominally chronostratigraphic units, these were effectively lithostratigraphic units recognized by characteristic fossils.

Ball (1900) cited the term 'Esna Shales' for the very widely represented claystone-dominated unit beneath the 'Unterlibysche Stufe', citing its use in (then unpublished reports) by the Egyptian Geological Survey (probably by Beadnell). It was first applied to a specific section in the Nile Valley by Beadnell (1905), in a description of the Gebel Awaina [Owaina] section, near Esna. Youssef (1954) formalized it as the Esna Shale Formation. Barron and Hume (1902) introduced the term Serai Limestone for a thick unit of limestone with flint in Wadi Qena (near Qena). This corresponds to the lower part of the later named Thebes Formation.

Said (1962) pointed out that Zittel's classification was essentially of rock rather than time-units, and introduced the first full formal lithostratigraphic terminology for the Eocene of Egypt, retaining Zittel's 'stufen' as Groups (Libya Group and Mokattam Group). The Libya Group included the Esna (Shale) Formation (not originally included in the Libysche stufe), and the newly named Thebes Formation and Minia Formation. The Thebes Formation was defined for the 'Lower Libyan' limestone with flint, with its type section defined as Gebel Gurnah. The Minia Formation was proposed for the Alveolina limestone ['Alveolinenkalk'], (Zittel's 'Oberlibysche stufe'), with a type section at Zawiet Sawada, on the right bank of the Nile opposite Minia, where it was described as 'snow-white limestone with abundant *Alveolina frumentiformis* and other larger foraminiferids (Said 1962, p. 96), and interpreted as Middle Eocene (Lutetian) on the basis of its echinoid assemblage.

Bishay (1961) differentiated two units between the Esna Formation and the Minia Formation on the eastern side of the Nile Valley between Samalut and Assiut, the lower Assiuti Chalk Formation, with flint layers and without macrofossils, and the upper Manfalut Formation (nummulitic limestone). These correspond to the Thebes Formation and Drunka Formation.

El-Naggar (1965) proposed a revised lithostratigraphic terminology. He renamed the Esna Shale the Owaina Shale Member, and classified its uppermost part, with interbeds of argillaceous limestone in the Thebes area, as the lowest unit of the Thebes Formation, the Thebes Calcareous Shale Member, naming the Thebes Formation (sensu Said 1960) as the Thebes Limestone Member.

Hermina and Lindenberg in Hermina et al. (1987) upgraded the Thebes Formation to Group rank, with regional variations in lithology differentiated as formations (including the Farafra Formation, introduced by Said (1962)). The Thebes Formation [designated on the maps as the Serai (Thebes) Formation], was shown as restricted to the Nile Valley and adjacent areas as the 'outer shelf chalk and chalky limestone facies, with chert layers'. The name Serai Limestone technically has priority over Thebes Formation, of which it is a synonym, but has effectively been abandoned.

Aubry et al. (2007) revised the lithostratigraphic terminology of the Esna Formation and its constituent units in the Nile Valley. They formally designated it as the Esna Shale Formation. The term 'shale', in the past often applied to any consolidated clay-grade sediment, strictly applies only to claystones with primary fissility, generally organic-rich. The Esna Formation is almost entirely 'blocky' and unbedded, as stated by Aubry et al. (2007) who chose to preserve a very well established lithologic name. Its apparent fissility on exposed surfaces is largely due to compaction-induced horizontal orientation of clay minerals, emphasised by expansion due to swelling and shrinking following water infiltration. Aubry et al. (2007) divided the Esna Shale Formation into four members. The Abu Had Member which directly underlies the Thebes Formation is renamed here the Qurnah Calcareous Shale Member (see addendum, Aubry and Dupuis, this paper).

The Thebes Formation

The characterization of the Thebes Formation/Group by chert nodules and layers seems a good regional character. The boundary with the Esna Shale formation is sharp. In contrast, the boundary with the Minia Formation needs detailed sedimentological study.

The Thebes Group, as introduced by the Geological Map of Egypt (1987), includes the Serai (Thebes) Formation, Rufuf Formation, Dungul Formation, Farafra Formation and Drunka Formation. Tawadros

(2001, p. 130) however concluded that these “formations' overlap or interfinger with one another” and that “In reality, all these formations are merely facies variations of the Thebes Formation”. The Farafra Formation is confined to parts of the Western Desert, and is not dealt with here. The status of the Rufuf, Dungul and Drunka Formations is discussed below, as is the Minia Formation which is not assigned to a Group by the Geological Map of Egypt.

Rufuf Formation

The type area of the Rufuf Formation is Naqb El Rufuf, on the escarpment bordering the eastern side of the Kharga Oasis. Although interpreted on the Geological Map of Egypt (1987) as a shallow-water facies, it was described by Tawadros (see 2012, p. 230) as comprising marls grading up to marly limestones and thick-bedded cherty limestones, and interpreted as a deep marine facies. Tawadros (2012) noted that the lithology is similar to the succession in the Luxor area, and rejected its separation from the Thebes Formation. From personal observations in Kharga Oasis at Darb Gaga and Gebel Um Goneima, the lithological succession and depositional environments in the lower and middle 'Rufuf Formation' (see details below) are closely comparable to those in the Thebes Formation of the Gebel Gurnah - Gebel Shaghab area of the Nile Valley, although flint nodules are almost absent and marl interbeds thicker in the lower part. As Tawadros concluded, the Rufuf Formation cannot be separated as a formation (or even member) entity from the Thebes Formation (s.s.).

Dungul Formation

South of latitude 25°, along the western side of the Nile Valley, the Thebes Formation is shown on the Geological Map of Egypt (1987) as grading laterally into the Dungul Formation. The Dungul Formation was introduced by Issawi (1968), with a type section at Wadi Dungul, 80 km WSW of Aswan. Here it comprises two distinct units, a lower interval of 'shale' with limestone interbeds, and an upper 'massive' limestone with flint nodules. The Geological Map of Egypt (1987), however, misleadingly stated that these intergrade laterally. It overlies the Garra Formation, dominantly limestone with marly interbeds. Said (1990, table 24.2) correlated the base of the Dungul Formation with the base of the Serai Formation at Wadi Qena [i.e., the base of the Thebes Formation]. The section in Wadi Abu Ghurra, 75 km NW of Aswan, including the Garra Formation and Dungul Formation, was studied in detail by Berggren et al. (2003). They identified the Paleocene/Eocene boundary at the top of the Garra Formation, on the basis of planktonic foraminifera. Here, as in the type area, the Dungul Formation comprises two distinct units. The lower Dungul Formation (Lower Clastic Member of Berggren et al. 2003) comprises a shallowing-upward sequence, from outer neritic clays to silts and clays with *Operculina*. Subzones P5c and P6a (lower Ypresian) are identified in the lower part of this interval. The upper unit ('Upper Calcareous member' of Berggren et al. 2003) comprises thick-bedded limestone with flint nodules and claystone interbeds. Larger foraminifera are common. Berggren et al. (2003) concluded that the boundary between these units corresponded to the Esna Formation/Thebes Formation boundary further north.

Along the scarp forming the eastern boundary of Kharga Oasis, north of approximately 24° 50’ N the Geological Map of Egypt (1987) has mapped the Esna Formation underlying the Thebes Formation. South of this latitude, a similar stratigraphic interval is mapped as the Garra Formation underlying the Dungul Formation (see also Hermina 1990, fig. 14.11). Here, as in the Aswan area, the base of the upper carbonate unit of the Dungul Formation is correlated with the base of the Thebes Formation. The uppermost Esna Formation in the Kharga Oasis and adjacent areas includes interbeds of argillaceous limestone and marl with *Operculina* and other larger foraminifera; this interval was named the Guss Abu Said Member by Tawadros (2001). It corresponds lithologically and in its depositional environment to the upper part of the 'Lower Clastic Member' of the Dungul Formation to the south.

From the foregoing summary, it is clear that:
1. The Dungul Formation is composite; the “lower clastic unit” and “upper carbonate unit” are lithologically distinct.
2. The “lower clastic unit” is transitional distally into the upper Esna Formation, and cannot be separated from it at formation level.
3. The “upper carbonate member” is a proximal representative of the Thebes Formation and cannot be separated from it at formation (or perhaps even member) level.
3. The Dungul Formation should therefore be abandoned.

Drunka Formation

The Drunka Formation was introduced by El-Naggar (1966) for limestones cropping out in the Nile Valley and adjacent areas between Qena and Assiut, and named from Gebel Drunka, SSW of Assiut. It was interpreted as overlying the Thebes Formation. It was adopted by the Geological Map of Egypt (1987) (e.g. the Assiut sheet), as part of the Thebes Group, and described as “Dense, thickly bedded platform limestone, locally reefal or lagoonal”. Said (1990) characterized it as comprising a lower massive poorly [macro] fossiliferous limestone and an upper “nodular and more fossiliferous” limestone with larger foraminifera (nummulitids and alveolinids).

Keheila and El-Ayyat (1990) and Keheila et al. (1991) studied several sections through the Drunka Formation in the Nile Valley to the north of Qena. Khalifa et al. (2004) studied four sections further north along the western border of the Nile Valley between Abu Tig, 20 km south of Assiut, and Mallawi, 90 km further north. They described it as “a distinct entity…characterized from all the [underlying] Lower Eocene carbonates by its massive, fossiliferous (especially the algal elements), bioturbated, porous and cavernous limestones”. “The Drunka Formation in the present area is composed of hard, crystalline, thick-bedded to massive limestone…The limestone is locally chalky and/ or argillaceous, highly bioturbated and highly fossiliferous. It contains chert concretions and bands. The base of the Drunka Formation [in this area] is unexposed, while its upper contact is conformable with the overlying Minia Formation at the Gebel Gibeil section. This contact is placed between the rosy white chalky, argillaceous, algal limestones of the upper unit of the Drunka Formation and the chalky white alveolinid limestones of the Minia Formation. Generally the limestone is very rich in calcareous green algae” (Khalifa et al., 2004, p. 236).

Keheila et al. (1991) and Khalifa et al. (2004) regarded the (middle and upper) Thebes Formation and the Drunka Formation as laterally interfingering and correlative units, rather than superposed. Khalifa et al. (2004) did not provide any field evidence for this, but Keheila et al. (1991) showed very schematic interfingering on their cross-sections (their figures 2 and 3). This was not based on detailed correlation between any of their logged sections, which they did not attempt, apparently assuming that all lithological units were lenticular, but presumably on the recurrence of Thebes-type lithologies within the Drunka Formation; this was not explicitly discussed. Their north-south Nile Valley cross-section (Keheila et al. 1991, fig. 2), apparently showing a progressive southward progradation of 'Drunka' facies at the expense of 'Thebes' facies, is misleading. Apart from their southernmost section, where the base of the Thebes Formation is exposed (judging by the Geological Map of Egypt), the base of each logged section is *within* the Thebes Formation, presumably at successively higher levels going northwards, due to the regional dip.

Biostratigraphic confirmation of the supposed relationship between the Thebes Formation and Drunka Formation was not possible; algal 'zones' differentiated within the Drunka Formation are equally likely to reflect environmental controls. Inspection of the logs in Keheila et al. (1991) indicates that in all sections there is an apparently abrupt upward change from the Thebes Formation to the algal and bioturbated limestones of the Drunka Formation. This suggests that this boundary represents a significant facies-shift, perhaps a sequence boundary. This implies that it is likely isochronous, and that the Drunka Formation and Thebes Formation are distinct and superposed lithostratigraphic units. Confirmation of this interpretation depends on further field study.

Minia Formation

The Minia Formation, originally defined as white limestone with abundant elongated *Alveolina* (Said 1962) is represented along the Nile Valley between Assiut and Minia, overlying the Drunka Formation. It comprises bioclastic limestones with larger foraminifera and calcareous algae. Boukhary et al. (2011, p. 1) commented that "the [lower boundary of the] Minia Formation is poorly defined and its significant paleontologic content is characterized by the presence of two large foraminiferal species, namely: *Alveolina frumentiformis* and *Orbitolites* cf. c*omplanatus*". Its lithological distinction from the underlying Drunka Formation has not been clearly established. In his study of Early Eocene *Nummulites* from the Nile Valley and other areas of Egypt, Boukhary et al. (2011, p. 22) also concluded that "new findings of *N. thalmanni* Schaub 1981 and *N.* gr. *subramondi* from the Minia Formation at Wadi El Gabrawi, Assiut environs enable workers to correlate the Minia Formation in Assiut environs with the Thebes Formation in Luxor-Sohag stretch". This conclusion was not discussed further, and is difficult to understand; these taxa are recorded only from a few sections and their vertical range seems poorly defined. Additionally, *N. thalmanni* is not cited from the Thebes Formation in the taxonomic section of their text.

Boundary between the Esna Formation and Thebes Formation

Said (1960) defined the base of the Thebes Formation "at the base of the massive limestone cliff exposed along the Nile Valley near Luxor. The break in slope [between calcareous claystone with thin argillaceous limestone beds and massive argillaceous limestone] is sharp and readily seen in outcrop" (Dupuis et al. 2003, p. 44). A comparable boundary can be identified throughout the sections in the Nile Valley and the Western Desert, and has been generally accepted (e.g. Aubry et al., 2007). El-Naggar (1966) however placed the base of the Thebes Formation at the base of the lowest limestone bed in the upper Esna Formation, as noted above.

The Abu Had (Chalk) Member was introduced by Abd El Razik (1972) as the lowest member of the Thebes Formation, illustrated by sections at Gebel Abu Had and Gebel Serai, bordering Wadi Qena, and Gebel Shaghab, south of Luxor. It was described as 'pink chalk and calcareous shale' (Abd El Razik 1972, p. 14). No type section was designated, but by comparison with other type sections designated by Abd El Razik, it was evidently intended to be at Gebel Abu Had. Here Abd El Razik's section indicates a thickness of c. 17 m, comprising a thick chalk unit overlain by a thin marly unit. At the nearby Gebel Serai, it comprises c. 20 m of chalk overlain by c. 23 m of marl (Abd El Razik 1972, plates 5, 6). Said (1990, table 24.2) correlated the Abu Had Member with the Hamidat Member of the Thebes Formation (see below). In the type area it was probably included by Keheila et al. (1991) in the Thebes Formation, although this is difficult to determine from their logs. Both here and at Gebel Serai, the Abu Had Member is clearly the lowest unit of the Thebes Formation, as originally classified.

Berggren and Ouda (2003b) analysed the biostratigraphy of the Paleocene and lowest Eocene of the Qreiya (Gebel Abu Had) section. They described the Esna Shale 3 as a 'foraminiferal calcarenite', c. 6 m thick, apparently a chalk with abundant planktonic foraminifera. They interpreted its basal surface as an unconformity, based partly on the apparent absence of the upper part of Zone P6b at this level. It is important to recognize that the Esna Shale 3 in Berggren and Ouda (2003b) does not correspond to the Abu Had Member of Abd El Razik (1972), which is included in the Thebes Limestone Formation. Correlation of the Esna Shale 3 with it in Aubry et al. (2007) was erroneous, the Abu Had Member of Abd El Razik clearly belonging to the Thebes Formation, rather than to the Esna Shale Formation, as shown by lithology and biostratigraphic data. The upper part of the Esna Shale Formation (= Esna Shale 3 in Dupuis et al., 2003) is renamed herein Qurnah Calcareous Shale Member; see Aubry and Dupuis, Addendum).

Further south in the Nile Valley, as at Gebel Gurnah and Dababiya, the highest interval of the Esna Formation comprises calcareous claystone with interbeds of marly limestone (Esna Shale 3 of Dupuis et al., 2003; = Qurnah Calcareous Shale Member). Here it has a sharp contact with the overlying Thebes Formation. Abd El Razik (1972, plate 4) identified the Abu Had Member at Gebel Shaghab, close to Dababiya. His log is difficult to interpret in detail, but as the underlying Shaghab Member (upper Esna Formation) was described as including 'intercalated by marly bands at top' (Abd El Razik 1972, p. 13), and his section profile clearly indicates a break in slope at its base, it is again clearly the lowest unit of the Thebes Formation.

Subdivision of the Thebes Formation in the Nile Valley

Khalifa (1970) mapped the Thebes Formation of Gebel El Shaghab, c. 30 km south of Gebel Gurnah. He differentiated three successive members: Hamidat Member: thinly-bedded marly limestone and limestone with flint (chert) nodules; Dababiya Member*:* massive chalky limestones with beds of *Operculina* biomicrudite; Shaghab Member: oyster limestones. These terms were first published in Omara et al. (1972). The Shaghab Member should not be confused with the El Shaghab Member of Abd El Razik (1972), applied to part of the upper Esna Formation (see Aubry et al., 2007, table 1). Abd El Razik (1972) divided the Thebes Formation into the Abu Had Member (chalk and marl) and the Serai Limestone Member. Based on his Gebel Shaghab section (pl. 4), the Abu Had Member here corresponds to the lower part of the Hamidat Member.

Snaveley et al. (1979) divided the Thebes Formation in the Nile Valley into lower, middle and upper units, regarded as informal members, illustrated by a diagrammatic columnar section (their fig. 2). The lower member comprised of chalk and marl with flints, corresponds to Units A, B and C of this paper (sii Fig. 8). The middle member corresponds to Units E to J and the lower part of Unit K. The upper member, including oyster coquinas, corresponds to the upper part of Unit K, and Units L and M. They noted the lateral persistence of the lower and middle members, with a southward increase in clay content in the lower member, associated with an increase in the proportion of skeletal limestones in the middle member in this area. The upper member was differentiated only in the more southerly sites. Comparable subdivisions were identified in the Gebel Duwi area in the Eastern Desert, but in generally shallower environments. Snaveley's three subdivisions were equated with the three members of Khalifa (1970) by Said (1990, table 24.2).

Keheila and El-Ayyat (1990) and Kehela et al. (1991) studied eight sections in the Thebes Formation and the Drunka Formation between Qena and Sohag and in Wadi Qena, to the north of Qena. Their study included petrographic and sedimentological analysis, and biostratigraphic study of larger foraminifera and calcareous algae (see also Biostratigraphy, below). Keheila et al. (1991) divided the Thebes Formation in this area into three successive lithofacies:

Lower lithofacies: A basal interval of marls with some calcareous claystone and chalk units, grading up to chalky limestone.

Middle lithofacies: lime mudstones and wackestones (bioclastic limestones) with many flint layers.

Upper lithofacies: interbedded silicified limestones and limestones, rich in larger foraminiferids and oysters.

This is very similar to the overall succession further south in Gebel Gurnah, as already recognized by Snaveley et al. (1979).

Appendix 2.

LeRoy (1953, fig. 2) described the Ain Maqfi section located at the northeastern escarpment of the Farafra Oasis (Western Desert). An approximately 132 m thick gray-green shale (the Esna Formation) is underlain by a thin (~2 m thick) limestone (Unit 3) and (~22 m thick) calcareous clay (Unit 4). Units 3 and 4 are bracketed by two prominent carbonate units which he designated Unit A (Maastrichtian chalks and limestones, below) and Unit I (an unnamed, tan to buff-colored indurated limestone with scattered *Nummulites, Flosculina* , i. al., with an incomplete/ minimum thickness of 42 m, above), subsequently designated the Farafra Limestone by Said and Kerdany (1961).

The lithostratigraphic succession between Units A below and Unit 1 above, were divided into three units said to be separated by erosional unconformities. They are, in ascending order:

Unit IV (~ 22 m thick): gray, calcareous shale with a benthic foraminiferal fauna allied with those of the Velasco Formation of Mexico (LeRoy, 1953: 8);

Unit III (~ 2 m thick): indurated, thin-bedded, limestone with *Nummulites deserti, Operculina libyca and Globorotalia velascoensis*;

Unit II (~ 132 m thick), Esna Shale); biostratigraphically subdivided into a (lower) *Bulimina farafraensis* fauna and an (upper) *Eponides lotus* fauna exhibiting affinities with (essentially contemporaneous) lower Paleogene faunal assemblages of the Midway and Wilcox faunas of the Gulf Coast.

Said and Kerdany (1961) described the planktonic foraminifera of the Farafra Oasis, designated the thin limestone Unit III near the base of the Esna Shale the Maqfi Limestone Member, extended I (and incorporated) the gray shales at the base to include Units III and IV, and assigned the upper 34 m alveolinid limestone of Unit I to the Farafra Limestone which had been described by Said (1960), and considered the reefal facies of the Ypresian in Egypt. In his review of the Cenozoic stratigraphy of Egypt (Said, 1990) considered that the Farafra Limestone at its type section at El Guss Abu Said, Farafra Oasis to belong to Zone P7; and to span the biostratigraphic interval of Zone P6a to P7 in Ezz El Orban well (Gulf of of Suez) and to P6b in the exposure at Gebel Thelmet and thus to replace the Upper Paleocene (Zone P5) part of the Esna Shale in these areas (see Said, 1990, Table 24.2, p. 457).

With the recognition of the presence/development of the Tarawan Chalk in the Ain Maqfi section by Youssef and Abdel-Aziz (1971), the stage was set for recognizing/achieving lower Paleogene lithostratigraphic extension between the Western Desert and Nile Valley. This was essentially achieved in the synoptic review of Strougo and Hewaidy (1999) from whom we have drawn heavily in this overview:

1. The Tarawan Chalk lies about 11-12 m below the Maqfi Limestone and allows the recognition of the Dakhla Shale below and between the Tarawan Chalk and the Campanian-Maastrichtian chalk near the near the base of Unit IV;

2. The Maqfi Limestone contains the earliest/lowest occurrence of *Nummulites, i. al. N. deserti, N. fraasi, N. solitarius, N. luterbacheri, N. praecursor, Discocyclina nudimargo,* Nummulitids are not known from any pre-Eocene levels in Egypt;

3. Benthic foraminifera in Unit IV contain, i.al, *Angulogavelinella avnimelechi, Marginulinopsis tuberculata, Gyroidinoides girardanus* which are restricted to Unit IV (and are known to have become extinct at the base of the PETM and Zone NP9a/b);

4. *Gaudryina africana, Marginulina carri, Cibicidoides pharaonis, Heterolepa libyca* and *Anomalinoides zitteli* have their LO in Unit III (Maqfi Limestone)

5. The Dakhla Shale, Tarawan Chalk, basal Esna Shale (LeRoy's Unit IV) should be assigned to the Paleocene; Unit III is younger and belongs to the Early Eocene, although it may contain nummulitid elements of slightly higher affinities (NP11-12)

Subsequent to the studies mentioned above a widespread search for a GSSP for the (base of the) Eocene led to a focus on stratigraphic sections in the Nile Valley (Egypt; Ouda and Aubry, 2003) and approval of a GSSP in the Dababiya Quarry of the Upper Nile Valley, about 35 km south of Luxor (Aubry et al. (2007). Of particular interest, and relevance, to regional litho- and biostratigraphic correlations between the Farafra Oasis (Western Desert) and Dababiya Quarry (and other sections in the northern Nile Valley) are the following:

1. Support for the recognition/correlation of Unit III (of LeRoy, 1953)= Maqfi Limestone Member (of Said and Kerdany, 1961) with the lowest/earliest nummulitids at the base of the Eocene, and thus with the Eocene GSSP (PETM) is seen in the biostratigraphic LO of *Morozovella subbotinae* (Morozova) (recorded as *Globorotalia simulatilis* (Schwager) by

LeRoy, 1953, pl. 9, figs 1-3 at the base of the Esna Shale (Unit II), sample Fcr-27A; Zone P5=E1-2; Berggren and Pearson, 2006a, 33); (cf. also Berggren and Norris, 1997, pl. 16, figs.9, 14, 21; Olsson et al., 1999, pl. 54, figs. 10-12; Berggren and Pearson, 2006b, pl. 11.1, figs. 13, 15; 14, 16).

2. In the Wadi Abu Ghurra section, southern part of the Upper Nile Valley (Berggren, Ouda, Obaidalla and Saad (2003) an ~ 2.5 m thick marly limestone contains an association of the PETM excursion fauna (*africana, allisonensis, sibaiyaensis)* together with several morozovelliid (*acuta,aequa, apanthesma, velascoensis*) and acarininid (*angulosa, esnaensis, soldadoensis, wilcoxensis)*, igorinid (*tadjikistanensis)* tax*a, Planorotalites pseudoscitula, Globanomalina luxorensis*, i..al.) overlain by an influx/LO of *Pseudohastigerian wilcoxensis.* Associated with the PF assemblage at the top of the PETM interval (Zone E1-2) is a low diversity assemblage of smaller and larger forms (discocyclinids, operculinids, primitive nummulitids) together with Midway benthic foraminiferal elements, mirroring conditions in the Maqfi Limestone at Farafra Oasis.

3. The Maqfi Limestone Member of the Western Desert is seen to be the lithostratigraphic and biostratigraphic equivalent of the Dababyia Quarry Member and the PETM (Table A). It occurs in the subsurface at Gebel Gurnah in the Tomb of Sennenmut (TT58) in front of the Temple of Hatshepsut (C. Dupuis, pers. obs., 2009).

Table caption

Table A. Extension and correlation of Paleocene-Lower Eocene lithostratigraphic units from the Western Desert (Farafra Oasis) to the Upper Nile Valley (Gebel Gurnah and Dababiya Quarry).

<table>
<tr><td colspan="2">Aubry et al., 2007</td><td>Aubry & Dupuis this paper</td><td>Said & Kerdany, 1961</td><td>Leroy, 1953</td></tr>
<tr><td colspan="3">Upper Nile Valley</td><td colspan="2">Western Desert</td></tr>
<tr><td colspan="2">Dababiya Quarry</td><td>Gebel Gurnah</td><td colspan="2">Farafra Oasis</td></tr>
<tr><td colspan="3">Thebes Limestone Formation</td><td rowspan="2">Farafra Limestone Formation</td><td>Unit I</td></tr>
<tr><td rowspan="4">Esna Shale Fm.</td><td>Abu Had Mb.(*)</td><td>Qurnah Member</td><td rowspan="2">Unit II</td></tr>
<tr><td colspan="2">El Mahmiya Member</td><td>Esna Shale Fm.</td></tr>
<tr><td colspan="2">Dababiya Quarry Member (PETM)</td><td>Maqfi Limestone (PETM)</td><td>Unit III</td></tr>
<tr><td colspan="2">El Hanadi Member</td><td>Esna Shale Fm.</td><td>Unit IV</td></tr>
<tr><td colspan="5">Tarawan Chalk Formation</td></tr>
<tr><td colspan="5">Dakhla Shale Formation</td></tr>
</table>

(*) see addendum

Appendix 3.

We present here a brief review of some of the more substantive studies of planktonic (PF) and Larger Benthic Foraminifera (LBF) of the Gebel Gurnah and nearby sections.

Planktonic Foraminifera

Said (1960) was the first to study the planktonic foraminiferal fauna of the Thebes Formation and the ~ 55m underlying Esna Shale Formation at Gebel Gurnah (including in its upper part the ~ 43m of "Thebes Calcareous Shale" of El Naggar (1966) (see comments above). Said (1960: 278) placed the Paleocene/Eocene boundary at the Esna/Thebes contact, based, no doubt, on his (mistaken) belief that *Globorotalia velascoensis* had its HO/LAD at this level (Said, 1960; 281, table 2). This was attributed by Krasheninnikov (personal communication to one of us, WAB, during a visit to Moscow in November 1963) to the misidentification of *Globorotalia aragonensis caucasica as Globorotalia velascoensis* by Said (1960, plate 2, figs. 2a-c) (or, as we think more likely, *Morozovella formosa* s. s., nominate taxon for Zone E4 from the Early/Lower Eocene).

Said (1960) recorded *Globigerina eoacaena, G. inaequispira, Globorotalia interposita, G. pentacamerata, G. pseudotopilensis, G. simulatilis* and *G. velascoensis* from the Esna Formation; *Globigerina triloculinoides* was recorded from both the Esna Formation and Thebes Formation. *Hastigerina micra, H. aspera, Globorotalia conicotruncata, G. imitata, G. planoconica* and *G. thebaica* n. sp. were recorded exclusively from the Thebes Formation. Given the state of taxonomy at the time, the preservation (Thebes Formation material is heavily coated by chalky material), and the inadequate quality of the line drawings, it is difficult to evaluate Said's determinations. However, we can venture the following statements/judgments:

1) *simulatilis =? gracilis*
2) *velascoensis=formosa s.s.*
3) *planoconica =Pseudohastigerina wilcoxensis*
4) *micra =?Ps. wilcoxensis*
5) *triloculinoides =patagonica? roesnaesensis complex*
6) *thebaica =?inaequispira*

It is curious that Said (1960) did not record *Acarinina interposita, A. pentacamerata* or *A. pseudotopilensis* in the Thebes Formation, as they are present in, and characteristic of, the lower to middle part of the formation (see below) but his work provided a starting point for subsequent studies.

The lower part of the exposed Esna Formation at Gebel Gurnah was subsequently ascribed to the *Globorotalia subbotinae* Zone, and the upper part to the *Globorotalia aragonensis* Subzone of the *Globorotalia aragonensis-Acarinina pentacamerata* Zone (Krasheninnikov and Ponikarov, 1965; see also Berggren, 1964). The overlying Thebes Formation was ascribed to the *Acarinina pentacamerata* Subzone by Krasheninnikov and Ponikarov (1965) and said to be characterized by, *i. al*. (with updated taxonomy), *Acarinina pseudotopilensis, A. triplex* (=*A. coalingensis*), *A. interposita, A. pentacamerata*, *Igorina broedermanni*, *Morozovella aragonensis, M. caucasica, Subbotina inaequispira*, *S. eocaena, S. pseudoeocaena* and *Globigerinella voluta* (=*Pseudohastigerina wilcoxensis*). Fahmy et al. (1969) subsequently and inexplicably equated both subzones to the entire Thebes Formation and ascribed to them a total thickness of 348m. It is not clear from these publications where the LO of *Morozovella aragonensis* (=base P7/E5) was recorded; i.e., ?within the upper Esna Formation or at the base of the Thebes Formation. Berggren and Ouda (2003a: 75, 77) recorded the LO of *M. aragonensis* about 40 m below the base of the Thebes Formation in the Dababiya Quarry.

A surprising find has been the (re)discovery of an apparently hitherto uncited PhD thesis (Hamam, 1971) dealing with the lower Eocene (Ypresian s.st.; i.e., post-CIE) biostratigraphy (planktonic foraminifera (PF) and larger benthic foraminifera (LBF) of the Gebel Gurnah section. Completed 40 years ago, this thesis contains a large amount of information of potential value and application to this, and related, studies. We present a review of this study insofar as it pertains to the present investigation.

Ninety species/taxa of PF are recorded/described, 13 of which are described as “new”. Hamam displayed a comprehensive familiarity with the current literature, both western and Soviet, and provided thorough reviews of comparative literature on the PF. While discussing the then modernization/nascent diversification of Paleogene PF taxonomy to reflect phylogenetic concepts (*Acarinina, Morozovella, Igorina, Pseudohastigerina*) in the publications of

McGowran, Subbotina, Berggren et al.. Hamam elected to remain with the typological classification of Bolli, Loeblich and Tappan, et al. For instance he includes *Globorotalia (Globorotalia), Globorotalia (Truncorotalia), Acarinina, Planorotalia, Planorotalites, Astrorotalia, Truncorotaloides* and *Morozovella* in the generic synonymy of *Globorotalia* (Hamam, 1971: 182). It will be recalled that the seminal paper on phylogenetic classification (with special reference to PF) by Steineck and Fleisher was not published until 1978 !. Hamam (1971), while retaining a conservative taxonomy, distinguished among/between "smooth'walled" and "rough walled" forms (subbotinids vs. acarininids) but lumped various distinct forms under "*Globorotalia*" (*Morozovella, Igorina*, keeled globanomalinids, etc.);

Hamam (1971: 20) built upon El Naggar's (1966) recently completed/published PhD thesis on the Gebel Owaina section and obviously consulted material he had deposited at the British Museum (Natural History) [now The Natural History Museum]. Six zones are recognized: *Gt. velascoensis, Gt. aequa, Gt. subbotinae, Gt .formosa, Gt.aragonensis* and *Gt. "palmerae*" . One can question the validity of identifying the latter zone, inasmuch as the nominate taxon was not recorded at Gebel Gurnah, and PF are absent or exceedingly rare/taxonomically indeterminate in his units IV-V and basal VI, and absent entirely in the remainder/upper part of Unit VI (upper part of the Thebes Formation; see Fig. 16).

Hamam (1971: chart 1) shows the HO of *Gt, formosa* and *Gt. subbotinae* (and the general disappearance of a large number of other PF) at the top of the Esna Formation. (N.B. Hamam used El-Naggar's (1966) lithostratigraphic terminology, in which the highest Esna Formation (as currently defined) was assigned to the Thebes Formation as the 'Thebes Calcareous Member'; see above, and Fig. 16). In this paper the current terminology is used with the Esna Shale/Thebes Limestone formational contact placed at the base of the massive carbonate buildup at the base of the Thebes unit). PF were said/shown to be rare in Unit III (lower part of the Thebes Formation) and recorded only in samples 29, 31, 33, 34, 36, 38, 44 and 46. (Unit III is Unit A of the present study; see Fig. 16). This interval was assigned to the *Gt. aragonensis* Zone, based on the persistence of this taxon to the top of the interval. Other forms continuing into Unit III include globanomalinids/pseudohastigerinids, "*Globigerina" triplex, G. interposita, G. angulosa* and a new species, *G. elnaggari.* The overlying units IV-VI (Units 5 to 23 of the present study) are assigned to the *Gt. "palmerae*" Zone (but see comments above). In Unit IV PF are much reduced and recorded only in samples 54, 55 and 63. The record of PF is somewhat better in Unit V (6 samples contain PF). Unit VI is virtually barren of PF, only one sample (119) containing identifiable PFs.

Hamam 1971) made an interesting observation in recording/describing three chiloguembelinid taxa in the *subbotinae* and *formosa* Zones and two guembelitriid taxa restricted to the *formosa* Zone. He listed the PF taxa in each zone; it must be noted that many anomalous names appear in some instances. These must be considered in the light of: 1) the antiquity of the study relative to advances in PF taxonomy in the nearly 40 intervening years; 2) poor preservation (*contra* statements to the contrary by Hamam throughout his thesis; much of the material from the Thebes Formation at Gebel Gurnah and other sections in Egypt is secondarily calcified, precluding accurate delineation of surface texture); 3) lack of SEM (illustrations were made by camera lucida drawing); 4) lack of comparative material (USNM, VNIGRI, etc.). Nevertheless, it is possible to evaluate several of Hamam's identifications and place them in a taxonomy consistent with recent/current work (Olsson et al. (1999) and Pearson et al. (2006).

Hamam (1971) recorded the presence of " *Globanomalina" wilcoxensis* as a "very rare" element in uppermost horizons of the *velascoensis* Zone. This could suggest that he recognized the overlap of *M. velascoensis* and *P. wilcoxensis* near the Paleocene/Eocene boundary, as first observed by Berggren (1964) in material from Gebel Gurnah and subsequently/currently used to denote a concurrent-range zone (E2) in the basal Eocene (Berggren and Pearson, 2005). However, as Berggren and Ouda (2003a: 75, 77) have shown, the HO of *Morozovella velascoensis* in the nearby Dababiya Quarry section occurs ~ 18 m above the base of the Dababiya Quarry Bed (=base PETM/CIE and base of Zone E1); the LO of *Pseudohastigerina wilcoxensis* (=base Zone E2) is at the top of the Dababiya Bed (~3.1 m above the base of the Dababiya Bed 1) and the overlap interval of *P. wilcoxensis* and *M. velascoensis* (=Zone E2) at Dababiya is about 11 m thick. The HO of *M. velascoensis* thus lies ~ 92 m below the Thebes Limestone Formation and ~ 65 m below the lowest limestone stringers of the so-called "Thebes Calcareous Shale Member of El Naggar. The record of "*Globorotalia velascoensis"* by Hamam (1971: 395, pl. 15, figs. 1a-c) (note that he also included *G. caucasica* in the synonymy of *M.*

velascoensis, which is now known to be quite incorrect) extends to ~ 43 m below the base of the Thebes Formation, which would suggest that the interval between the HO of *G. velascoensis* and the base of the Thebes Formation thins from ~ 92 m to ~ 43 m between Dababiya Quarry and Gebel Gurnah. It is of interest that Hamam (1971: 48) noted that the lower limit of the *G. velascoensis* Zone was not exposed in the Gebel Gurnah section, only 3.36 m being visible. Hamam (1971) concludes his study with a numerical/quantitative analysis of several categories of PF. While the indiscriminant lumping of several distinct taxonomic categories precludes the use of resulting ratios for precise paleoecologic analysis (stable isotope analysis was in its infancy at this time) several generalizations can be made:

i. PF dominate the foraminiferal assemblages throughout the exposed Esna Formation, and exhibit a general increase in diversity upwards in this interval.

ii. acarininids dominate the Esna Formation PF assemblages.

iii. P/B ratios show a general increase towards the top of the Esna Formation.

iv. PF reach their maximum frequency in the middle of the *formosa* Zone.

v. keeled forms never exceed 11.3% of the total PF and exhibit a general increase towards the top of the Esna Formation.

vi. acarininids reach maximum frequency in the middle of the *subbotinae* Zone and upper part of the *formosa* Zone and exhibit general increase upwards in the Esna Formation.

The P/E boundary was not exposed below/in front of the Temple of Deir el Bahari at the time of this thesis work, as can be seen in the fact that the HO of *Morozovella velascoensis* occurs in sample 2 of Hamam (1971: 424, chart 1) ~3 m above the base of the section and ~2 m below the base of the “Thebes Calcareous Shale”. At Dababiya the HO of *M. velascoensis* occurs at ~18 m above the P/E=onset of the CIE and ~ 50 m below the base of the equivalent of the "Calcareous Shale”. The P/E boundary (=the PETM in the form of the Dababiya Quarry Beds is, in fact, exposed in the tomb of Senenmut, adjacent to the Temple of Deir el Bahari (personal observation, Ch. Dupuis, 2009; see also Appendix 2 above)

Larger Benthic Foraminifera (LBF)

Several interesting contributions have discussed the taxonomy and stratigraphic ranges of LBF at Gebel Gurnah and nearby sections. Hamam (1971) observed that no LBF were found in the Esna Shale nor in the lower part (his unit III; our unit B-D (see Figure 16, this paper, in the discussion here and below) of the Thebes Formation, but that they occur (well preserved) in Unit IV (his samples 57, 59, 62, 64, 65, 67, 68; our unit D-lower H) where they are always associated with well-preserved ostracode faunas. Unit V (our unit H-K) has LBF in samples 84, 87 and 89. Unit VI (our unit K-M) has very poor fauna and no LBF. He also identified seven species, one subspecies and one variety. These are 1) *Nummulites burdigalensis N. globulus, N. silvanus, N. subramondi, N. aff. solitarius* (megalospheric forms only, except for *burdigalensis* which also exhibits microspheric generation); and 2) *Operculina jiwani nakhiensis, O. libyca, N. libyca thebensis, O. aegyptiaca (*megalospheric forms only except for *libyca* which also exhibits microspheric generation). He determined that the LBF assemblage is characteristic of Lower Eocene (Ypresian/Cusian) and correlative with the *Nummulites planulatus* “Zone” of NW Europe Cuisian which is, in turn, correlative with Zones NP11-12 (= P6b-P7/E4-E5) (Aubry, 1986; see discussion below).
Hamam (1971, 1975) identified three species of *Operculina* and five species of *Nummulites* from the upper part of the Thebes Formation in Gebel Gurnah, indicating an Early Eocene (Ypresian) age. He recorded *N. silvanus* [probably *N. praecursor* of later publications] from samples 57-84 (lower Unit C to upper Unit H) and *N. subramondi* from samples 84-89 (upper Unit H and Unit J).

Kenawy (1976) summarized earlier studies on the Thebes Formation. He recorded three species of *Nummulites* from the middle and upper Thebes Formation in Gebel Shaghab, *N. atacicus* [probably *N. subramondi*, whose types are from nearby Gebel Deir], *N. globulus* (stated to be very common at the top) and *N. solitarius*. Their vertical distribution was not clearly specified, although they apparently occur together. He dated this assemblage as early Ypresian. These and earlier studies were cited by Blondeau et al. (1982), who analyzed *Nummulites* assemblages from three sections between Luxor (Gebel Gurnah) and Qena. These authors differentiated three successive populations, characterized respectively by *Nummulites praecursor*, *N. atacicus* and *N.* aff. *planulatus*. The lower two assemblages were identified at Gebel Gurnah, *N. atacicus* at Gebel Nagada and *N.* cf. *planulatus* at Gebel Dandara, the most northerly site. As noted above, *N. atacicus* has been identified as *N. subramondi* in other publications. No details of vertical distribution were provided; the two populations from Gebel Gurnah were described only as from 'near the base' and near the top' of the section, but it is likely that they were from the middle and upper part of the Thebes Formation, by comparison with the results of Hamam (1971, 1975) and the distribution of *Nummulites* established by the present study.

Keheila et al. (1991) differentiated two successive *Nummulites* assemblages in the middle and upper Thebes Formation of sections between Qena and Sohag, following Kenawy (1972): the *Nummulites solitarius* Zone (with *N. fraasi* ['*frassi*'] and *N. pratti*) and the *N. planulatus*/ *N. burdigalensis* Zone (with *N. atacicus*). These were interpreted as lower and upper Ypresian respectively. Based on Serra-Kiel et al. (1998), the *N. solitarius* Zone equates to SBZ5-6 (lowermost Ypresian) (although *N. prattii* is SBZ 11-12 !) and the *N. planulatus/burdigalensis* Zone to SBZ10 (middle Ypresian).

Boukhary et al. (2011) did not refer to the study of Blondeau et al. (1982) but recorded the new species *Nummulites luxorensis* from Deir El Bahari (Gebel Gurnah), at a level probably within Unit H (Boukhary et al. 2011, fig. 4). They reassigned *N. atacicus* of earlier publications to *N. subramondi* and interpreted *N.* aff *planulatus* as a new species, *N. dandaraensis*, from the highest part of the Thebes Formation at Gebel Dandara. They interpreted the ranges of *N. subramondi*, *N. praecursor* and *N. dandaraensis* as coeval (Boukhary et al. 2011, fig. 13), but no evidence for this was presented. All were assigned to Zone SBZ 10 (mid -Ypresian), although this is not consistent with Serra-Kiel et al. (1998) who assigned *N. praecursor* to SBZ 7 and *N. subramondi* to SBZ 8-9. Identification of *N. praecursor* is discrepant with the microfaunal and nannofossil dating of the record of *N. rotularius* and *N. subramondi* from the 'Thebes Formation' [Drunka Formation] at Gebel Drunka (Boukhary et al. 2011, fig. 6). The Minia Formation was referred to SBZ 11 and SBZ 12 by Boukhary et al. (2011); *Alveolina frumentiformis*, a key fossil of the Minia Formation, was assigned to SBZ 12-lower SBZ 13 (latest Ypresian) by Serra-Kiel et al. (1998).

At present the validity of *Nummulites* species for correlation or dating in the Thebes Formation seems unclear. There are discrepancies due to differing identification of taxa by different workers and with the age assignments of individual taxa; the SBZ Zones are also not all accurately calibrated with the nannofossil zonation or other biostratigraphic criteria (Vandenberghe et al. 2012).

Appendix 4.

We attempt here to reconstruct an estimated biochrononologic framework for the lithologic sucession and planktonic foraminiferal and calcareous nannoplanton biostratigraphy. In the discussion below the following abbreviations are used for brevity: (PF) BKSA95: Berggren, Kent, Swisher and Aubry, 1995; BM88: Berggren and Miller, 1988; BP05: Berggren and Pearson, 2005; WPBP11: Wade, Pearson, Berggren and Pälike, 2011).

1a. The base of Zone E5 (*Morozovella aragonensis/Morozovella subbotinae* Concurrent-range is based on the LO of *M. aragonensis.* Formerly Zone P7, it was based on the concurrent range of *M. aragonensis* and *M. formosa.* However, the taxon *M. subbotinae* was substituted by BP05:290, for *formosa* (whose rarity and taxonomic identity is difficult to determine in the terminal part of its range but whose HO occurs together with other morozovellids (i. al., *gracilis, marginodentata*).

1b. At Gebel Gurnah Hamam (1971) recorded the HO of *Morozovella formosa* and the LO of *M. aragonensis* in sample 20 at the base of the Thebes Limestone *s.s* (his Unit II), about 41 m above the base of the Thebes Calcareous Shale Member (= Abu Had Member of Aubry et al. [2007] = Qurnah Shale Member of this paper) of the Esna Shale Formation, and about 46 m above the base of the section collected by Hamam (1971) in the Upper Esna Shale with a *Morozovella velascoensis* fauna. In this study we have identified *M. aragonensis* 3 m below the base of the Thebes Limestone Formation *s.s.*

1c. In the Dababiya Quarry section (BO03), the HO of *M. formosa* and the LO of *M. aragonensis* (E4/E5 zonal boundary) occur ~ 9 m and 24 m, respectively, below the Esna Shale /Thebes Limestone formational contact, i.e., within the Qurnah Calcareous Shale Member. We did not observe *formosa* in the Gebel Gurnah section and *gracilis* and *subbotinae* occur only rarely in lithologic Unit A. Thus, the morozovellids (and, indeed, the planktonic foraminifera in general) play only a minor role in deciphering/delineating the biostratigraphic history of the Thebes Formation. However, we can be confident in placing the base of the formation and the upper part of the subjacent Qurnah Calcareous Member within (PF) Zone P7 (of BM88= BKSA95) = E5 (of BP05 and WPBP11).

2. The base of Zone NP12 is defined by the LO of *Heliodiscoaster lodoensis*. This species is extremely rare in Upper Egypt, but it occurs in the Thebes Limestone Formation as

well as in the upper part of the Esna Shale Formation (Qurnah Calcareous Shale Member) at Gebel Gurnah (El Dawoody, 1993, this paper, and MPA pers. observation in the QCSM). We estimate from El Dawoody (1993, Fig. 2) that the LO of *H. lodoensis* is located ~8 m below the base of the Thebes Limestone Formation in this section.

3. The base of the Thebes Limestone is thus seen to lie well above the NP11/12 (LO of *Heliodiscoaster lodoensis*) and within E5 (LO of *Morozovella aragonensis*) boundaries. The close juxtaposition of these two taxa mirrors that seen in standard biostratigraphies (e.g., BKSA95: 140, Fig. 2; BP05: 290, Fig. 2).

4. The upper extension of Zone NP12 at Gebel Gurnah cannot be established confidently because of the sharp drop in abundance of *T. orthostylus* and reduction in diversity above 178 m (this work). However the lower 178 m of the Thebes Limestone Formation are firmly assigned to Zone NP12. The next stratigraphic level confidently dated by calcareous nannofossils lies at 232 m based on the co-occurrence of *H. lodoensis* together with *H. cruciformis* in the absence of *T. orthostylus*.). Thus, there is an approximately 74 m stratigraphic interval with no determinable biostratigraphy. However, the NP12/NP13 boundary lies within this 74 m as well as the stratigraphic interval equivalent to the absent Zone P8/E6 (owing to the absence of the definitive bracketing zonal taxa, *M. subbotinae* (base), *Ac. cuneicamerata* (top) and partial range of *Ac. pentacamerata*. The biostratigraphic/zonal interval of the E6 (*Acarinina pentacamerata)* zonal interval (where represented) straddles the N12/13 boundary interval (BKSA95: 140; Fig. 2). Inasmuch as Zone P8/E6 has an estimated duration of 0.4 Myr between 50.8-50.4 Ma we may assume that this zonal interval is correlative with the upper portion of the stratigraphic interval between 178 and 232 m at Gebel Gurnah. However, based on the information at hand we can only show the correlative limits of Zone P8/E6 below 178 m and above 232 m (i.e, spanning but exceeding/bracketing the limits of the NP12/13 boundary interval (see Fig. 11).

5. The base of the Thebes Limestone Formation is bracketed by the FAD of *M. aragonensis* and the Sequence boundary at the top of Unit A of the formation which we have correlated with Sequence Boundary (SB) Yp6 . We estimate that the base of the formation (*sensu* Said, 1960) is ~52.45 Ma and the top (*sensu* Said, 1960, at 338 m) is younger than the base of (global) SB Yp 10 at 49.6 Ma (Table 3). However, we have redefined the top of the formation so as to correspond to level 326 m which records the SB Yp10 and to allocate the

overlying beds to the Minia Limestone Formation. The Thebes Limestone Formation at Gebel Gurnah, thus, has an estimated duration of ~2.8 Myr, in the late Early Eocene.